DNNDK User Guide

UG1327 (v1.6) August 13, 2019

Revision History

The following table shows the revision history for this document.

Section	Revision Summary
08/13/2019 Version 1.6	
Chapter 1: Quick Start	• Updated the example package name and folder description for the DNNDK v3.1 release. • Added a description of Avnet ZedBoard. • Updated Table 1 and installation description of the host. • Removed description of Wifi connection steps • Added the sample description back to the document. • Updated figures.
Chapter 2: Copyright and Version	• Updated board information. • Updated component version information. • Added information on two new tools, DLet and DDump.
Chapter 4: DNNDK	• Added description of Python APIs • Updated Figure of DNNDK toolchains.
Chapter 5: Network Deployment Overview	• Updated description of network compress (TensorFlow version). • Updated figures.
Chapter 6: Network Compression	• Updated DECENT Overview. • Updated DECENT (TensorFlow Version) Usage. • DECENT (TensorFlow Version) Working Flow
Chapter 7: Network Compilation	• Added Using DLet. • Updated Tables on DNNC Compilation Mode. • Added DPU Shared Library.
Chapter 8: Programming with DNNDK	• Updated Programming Model of DPU Tensor. • Updated Programming Interface.
Chapter 11: Utilities	• Added description of DDump. • Updated figures. • Updated description of the follow APIs: • dpuCreateTask() • dpuGetTensorAddress() • dpuGetTensorScale() • dpuSetInputImageWithScale()
Chapter 13: Python Programming APIs	• Added new chapter.

06/07/2019 Version 1.5	
Chapter 1: Quick Start	• Updated the example package name for the DNNDK v3.0 release. • Added a note in the Installing the DNNDK Host Tools section. • Updated Figure 2.
Chapter 2: Copyright and Version	• Updated board information. • Updated component version information.
Chapter 7: Network Compilation	• Updated the `--dpu` parameter description.
04/29/2019 Version 1.4	
Chapter 1: Quick Start	• Removed all content related to DP-8020 and DP-N1 boards. • Updated installation information; added installing TensorFlow version details. • Updated information for Ultra96, ZCU102, and ZCU104 boards. • Removed DNNDK examples.
Chapter 2: Copyright and Version	• Updated board information. • Updated component version information.
Chapter 3: Upgrading and Porting	• Added information about Upgrading from v3.0.
Chapter 5: Network Deployment Overview	• Added TensorFlow model information. • Added information about network compression for TensorFlow version. • Added content about compiling Caffe ResNet-50 and TensorFlow ResNet-50. • Updated Output Kernels. • Updated Programming with DNNDK.
Chapter 6: Network Compression	• Updated DECENT Working Flow. • Updated information about using DECENT for Caffe version. • Added information about DECENT_Q for TensorFlow version.
Chapter 7: Network Compilation	• Updated information about using DNNC with both deployment and dummy compilation modes. • Updated details about compiling ResNet50.
Chapter 13: Python Programming APIs	Added v2.06 information to the following APIs: • dpuSetInputTensorInCHWInt8() • dpuSetInputTensorInCHWFP32() • dpuSetInputTensorInHWCInt8() • dpuSetInputTensorInHWCFP32() • dpuGetOutputTensorInCHWFP32()

	• dpuGetOutputTensorInHWCInt8() • dpuGetOutputTensorInHWCFP32() • dpuSetInputImage() • dpuSetInputImage2()
02/28/2019 Version 1.3	
Downloading DNNDK	Added DNNDK support for non-GPU host machines.
$dnndk_pkg	
Chapter 3: Upgrading and Porting	
Network Compression	
DECENT Overview	
02/19/2019 Version 1.2	
Downloading DNNDK	Updated links to Xilinx product page with information about DNNDK-supported evaluation boards.
Setting Up the Evaluation Board	
Setting Up the DP-8020 Evaluation Board	
Setting Up the DP-N1 Board	
02/07/2019 Version 1.1	
$dnndk_pkg	Updated information. Added liability notice.
01/22/2019 Version 1.0	
General updates	Initial Xilinx release.

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Downloading DNNDK

The Deep Neural Network Development Kit (DNNDK) package can be freely downloaded after registration from the Xilinx website: https://www.xilinx.com/products/design-tools/ai-inference/edge-ai-platform.html.

Using a DNNDK-supported evaluation board is recommended to allow you to become familiar with the DNNDK toolchain. Refer to https://www.xilinx.com/products/design-tools/ai-inference/ai-developer-hub.html#edge for more details about the DNNDK-supported evaluation boards.

The package name for the DNNDK v3.1 release is `xilinx_dnndk_v3.1_yymm.tar.gz`, in which *yy* is the year and *mm* is the month. For example, the current released package name is `xilinx_dnndk_v3.1_1908.tar.gz`.

The directory structure for the DNNDK release package is shown in the following figure. In the rest of this document, `$dnndk_pkg` is used to represent the name of `xilinx_dnndk_v3.1` for simplicity.

The evaluation boards supported for this release are:

- Xilinx ZCU102
- Xilinx ZCU104
- Avnet ZedBoard
- Avnet Ultra96

The `host_x86` folder contains files that need to be copied to the host computer running the 64-bit version of Ubuntu 14.04 LTS or Ubuntu 16.04 LTS or Ubuntu 18.04 LTS.

The `<board_name>` folder contains files to be used on the evaluation board. The actual name of the folder corresponds to the DNNDK-supported boards: ZedBoard, `Ultra96`, `ZCU102`, or `ZCU104`. Utility tools, Deep-learning Processor Unit (DPU) drivers, DPU runtime and development libraries are device-specific, and will be different for the various boards.

```
$dnndk_pkg
        | -- COPYRIGHT
        | -- host_x86
        |     | -- install.sh
        |     | -- models
        |     | -- dcf
        |     | -- pkgs
        |          |-- ubuntu14.04
        |          |-- ubuntu16.04
        |          |-- ubuntu18.04
        | -- board_name
             | -- install.sh
             | -- pkgs
             |     | -- bin
             |     | -- driver
             |     | -- include
             |     | -- lib
             | -- samples
                   | -- common
                   | -- mini_resnet
                   | -- inception_v1_mt
                   | -- resnet50
                   | -- video_analysis
                   | -- segmentation
                   | -- adas_detection
```

Setting Up the Host

The "host_x86" folder contains the Deep Compression Tool (DECENT) and Deep Neural Network Compiler (DNNC) host tools, which allow neural networks to be optimized and accelerated on the DPU inference engine. And utilities tools DDump and DLet are introduced since DNNDK v3.1.

IMPORTANT: *Carefully read the capitalized text that follows.*

NOTICE: BY RUNNING THE COMMAND BELOW, YOU WILL CAUSE TO BE DOWNLOADED AND INSTALLED ON YOUR MACHINE CERTAIN THIRD-PARTY OPEN SOURCE SOFTWARE GOVERNED EXCLUSIVELY BY OPEN SOURCE LICENSES. BY RUNNING THE COMMAND BELOW AND DOWNLOADING AND USING THE THIRD-PARTY OPEN SOURCE SOFTWARE, YOU AGREE ON BEHALF OF YOURSELF AND YOUR EMPLOYER (IF APPLICABLE) TO BE BOUND BY THIS INFORMATION AND THE OPEN SOURCE LICENSE AGREEMENTS APPLICABLE TO THE SPECIFIC THIRD-PARTY SOFTWARE INSTALLED ON YOUR MACHINE. IF YOU OR YOUR EMPLOYER DO NOT AGREE TO ALL OF THE INFORMATION AND APPLICABLE OPEN SOURCE LICENSE AGREEMENTS, DO NOT RUN THIS COMMAND.

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Installing the GPU Platform Software

The current DNNDK release can be used on the X86 host machine with or without GPU. With GPU support, DECENT is able to run faster.

If GPU is available in the X86 host machine, install the necessary GPU platform software in accordance with your GPU product documentation. Ensure all versions are compatible with the version of DNNDK. For questions, contact your account manager or submit a support case to https://www.xilinx.com.

Caffe Version: Installing Dependent Libraries

Run the following command to install the dependent libraries required by Caffe v1.0.

```
$ apt-get install -y --force-yes build-essential autoconf libtool libopenblas-
dev libgflags-dev libgoogle-glog-dev libopencv-dev protobuf-compiler libleveldb-
dev liblmdb-dev libhdf5-dev libsnappy-dev libboost-all-dev libssl-dev
```

TensorFlow Version: Installing with Anaconda

The DECENT_Q for TensorFlow supports operating system of Ubuntu 14.04 and 16.04 platforms, and have both CPU and GPU versions. Xilinx provides installation packages for common environments listed below, users can download the right package. If you are working under other environments, contact Xilinx.

Table 1: Supported 64-bit Host OS Platforms and Required Packages

OS Platform	Version	Required Packages	Python	Package Name
Ubuntu 14.04 LTS	GPU	CUDA 10.0, cuDNN 7.4.1	2.7	tensorflow_gpu-1.12.0-cp27-cp27mu-linux_x86_64.whl
			3.6	tensorflow_gpu-1.12.0-cp36-cp36m-linux_x86_64.whl
	CPU Only	None	2.7	tensorflow-1.12.0-cp27-cp27mu-linux_x86_64.whl
			3.6	tensorflow-1.12.0-cp36-cp36m-linux_x86_64.whl
Ubuntu 16.04 LTS	GPU	CUDA 9.0, cuDNN 7.0.5	2.7	tensorflow_gpu-1.12.0-cp27-cp27mu-linux_x86_64.whl
			3.6	tensorflow_gpu-1.12.0-cp36-cp36m-linux_x86_64.whl
	CPU Only	None	2.7	tensorflow-1.12.0-cp27-cp27mu-linux_x86_64.whl
			3.6	tensorflow-1.12.0-cp36-cp36m-linux_x86_64.whl

Ubuntu 18.04 LTS	GPU	CUDA 10.0, cuDNN 7.4.1	2.7	tensorflow_gpu-1.12.0-cp27-cp27mu-linux_x86_64.whl
			3.6	tensorflow_gpu-1.12.0-cp36-cp36m-linux_x86_64.whl
	CPU Only	None	2.7	tensorflow-1.12.0-cp27-cp27mu-linux_x86_64.whl
			3.6	tensorflow-1.12.0-cp36-cp36m-linux_x86_64.whl

Anaconda provides the conda utility to create a virtual environment. It is recommended to create a new anaconda environment and use the `pip install` command to install DECENT_Q in case of affecting the existing TensorFlow versions. Once you have anaconda installed (see https://www.anaconda.com for instructions), use the following commands to install DECENT_Q inside a virtual environment:

```
$ conda create -n decent pip python=2.7 # or python=3.6, etc.
$ source activate decent
(decent)$ pip install ${DECENT_Q_TF_PKG}
(decent)$ pip install numpy opencv-python sklearn scipy progressbar2 # install
prerequisites
```

where DECENT_Q_TF_PKG is the downloaded installation package.

Note: You can run the tool with `--help` to validate your installation:

```
(decent)$ decent_q  --help
```

Installing the DNNDK Host Tools

After downloading and unpacking the DNNDK package, execute the sudo `./install.sh` command under the `host_x86` folder to install the DECENT,DNNC, DDump and DLet tools on the host.

Setting Up the Evaluation Board

Supported Evaluation Boards

The following sections describe the evaluation boards supported by DNNDK. The ZedBoard and Ultra96 are intended for evaluating low-power, low-throughput deep learning applications. The Xilinx ZCU102 and ZCU104 are geared towards higher throughput deep learning inference requiring low latency.

The SD card system image files for all DNNDK supported evaluation boards are available for download from https://www.xilinx.com/products/design-tools/ai-inference/ai-developer-hub.html#edge. Before trying DNNDK v3.1 on the evaluation boards, you must download the suited version image file; otherwise, DNNDK package cannot work on the previous version image file.

Note: Before installing DNNDK v3.1 into your evaluation board, download the updated version image file from https://www.xilinx.com/products/design-tools/ai-inference/ai-developer-hub.html#edge.

Setting Up the Zed Board

ZedBoard is a complete development kit for designers interested in exploring designs using the Xilinx Zynq®-7000 SoC. This board contains all the necessary interfaces and supporting functions to enable a

wide range of applications. The expandability features of the board make it ideal for rapid prototyping and proof-of-concept development. The hardware documentation for ZedBoard is available for download on http://zedboard.org/product/zedboard.

The main connectivity interfaces for ZedBoard are shown in the following figure.

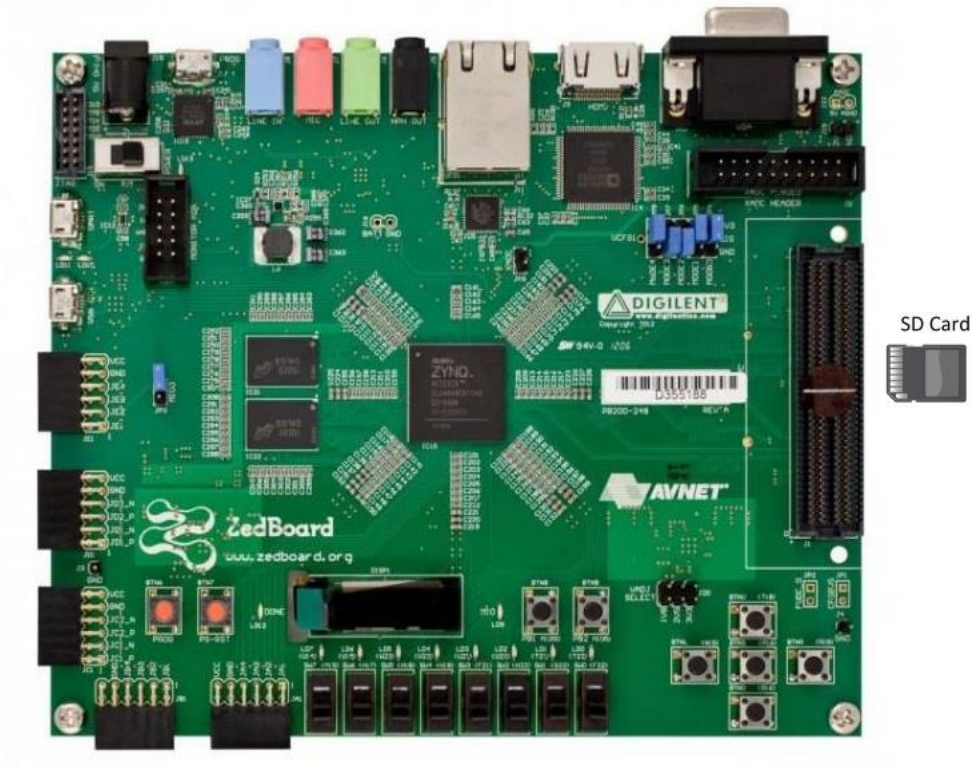


Figure 1: ZedBoard Evaluation Board and Peripheral Connections

The DPU signature information is shown in the following figure. One DPU core running at 90 MHz is implemented on the Xilinx Zynq-7020 device. Limited by the hardware resources of the chip, examples provided by ZedBoard include resnet50, inception_v1_mt, and face_detection. which are different from other boards.

```
root@zedboard-dpu-trd-v2019-1:~# dexplorer -w
[DPU IP Spec]
IP  Timestamp           : 2019-08-07 21:00:00
DPU Core Count          : 1

[DPU Core Configuration List]
DPU Core                : #0
DPU Enabled             : Yes
DPU Arch                : B1152
DPU Target Version      : v1.4.0
DPU Freqency            : 90 MHz
Ram Usage               : Low
DepthwiseConv           : Disabled
DepthwiseConv+Relu6     : Disabled
Conv+Leakyrelu          : Disabled
Conv+Relu6              : Enabled
Channel Augmentation    : Enabled
Average Pool            : Enabled
```

Figure 2: ZedBoard DPU Signature Viewed with DExplorer

Setting Up the Ultra96 Board

Ultra96 is an Arm®-based, Xilinx Zynq® UltraScale+™ MPSoC development board based on the Linaro 96Boards specification. The 96Board specifications are open and define a standard board layout for development platforms that can be used by software application, hardware device, kernel, and other system software developers. Ultra96 represents a unique position in the 96Boards community with a wide range of potential peripherals and acceleration engines in the programmable logic that is not available from other offerings. The hardware documentation for Ultra96 is available for download on http://zedboard.org/product/ultra96.

The main connectivity interfaces for Ultra96 are shown in the following figure.

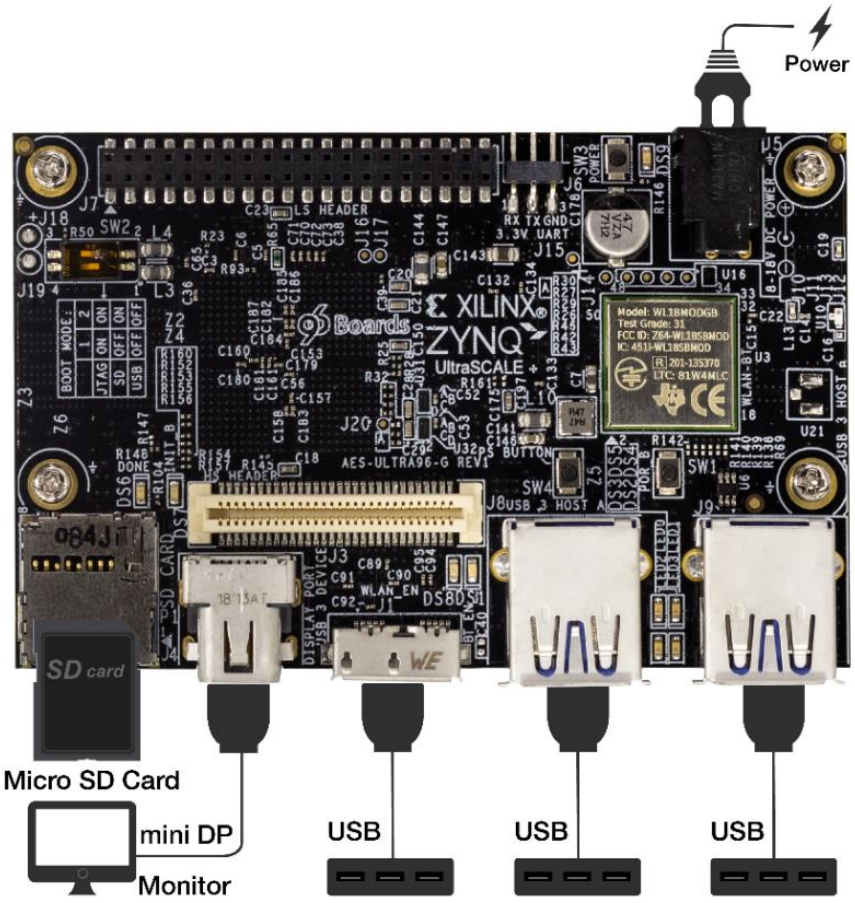


Figure 3: Ultra96 Evaluation Board and Peripheral Connections

The DPU signature information is shown in the following figure. One DPU core running at 325 MHz is implemented on the Xilinx ZU3 device.

```
root@xilinx-ultra96-v2019:~$dexplorer -w
[DPU IP Spec]
IP  Timestamp           : 2019-07-25 16:00:00
DPU Core Count          : 1

[DPU Core Configuration List]
DPU Core                : #0
DPU Enabled             : Yes
DPU Arch                : B1600
DPU Target Version      : v1.4.0
DPU Freqency            : 325 MHz
Ram Usage               : Low
DepthwiseConv           : Enabled
DepthwiseConv+Relu6     : Enabled
Conv+Leakyrelu          : Enabled
Conv+Relu6              : Enabled
Channel Augmentation    : Disabled
Average Pool            : Enabled
```

Figure 4: Ultra96 DPU Signature Viewed with DExplorer

Setting Up the ZCU102 Evaluation Board

The Xilinx ZCU102 evaluation board uses the mid-range ZU9 UltraScale+ device to enable you to jumpstart your machine learning applications. For more information on the ZCU102 board, refer to the ZCU102 product page on the Xilinx website: https://www.xilinx.com/products/boards-and-kits/ek-u1-zcu102-g.html.

The main connectivity interfaces for ZCU102 are shown in the following figure.

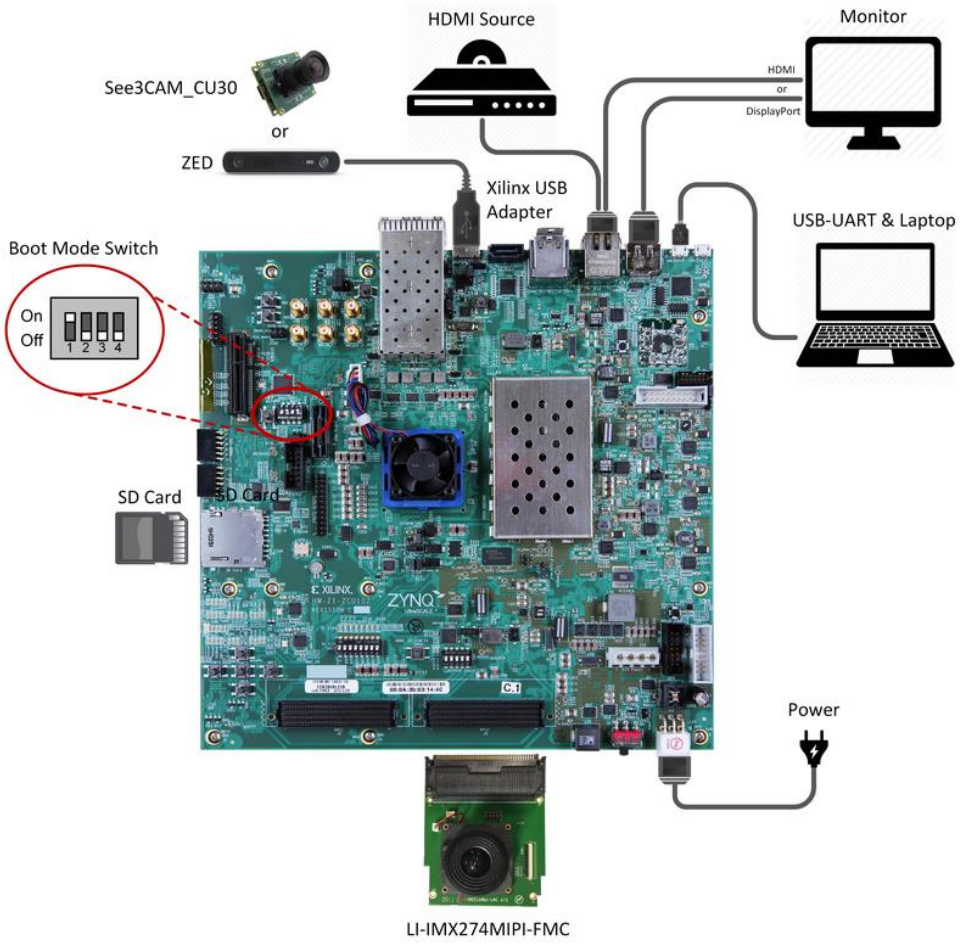


Figure 5: Xilinx ZCU102 Evaluation Board and Peripheral Connections

The DPU signature information is shown in the following figure. Triple DPU cores running at 325 MHz are implemented on the Xilinx ZU9 device.

```
root@xilinx-zcu102-2019_1:~$dexplorer -w
[DPU IP Spec]
IP  Timestamp           : 2019-07-24 11:15:00
DPU Core Count          : 3

[DPU Core Configuration List]
DPU Core                : #0
DPU Enabled             : Yes
DPU Arch                : B4096
DPU Target Version      : v1.4.0
DPU Freqency            : 325 MHz
Ram Usage               : Low
DepthwiseConv           : Enabled
DepthwiseConv+Relu6     : Enabled
Conv+Leakyrelu          : Enabled
Conv+Relu6              : Enabled
Channel Augmentation    : Enabled
Average Pool            : Enabled

DPU Core                : #1
```

Figure 6: Xilinx ZCU102 DPU Signature Viewed with DExplorer

Setting Up the ZCU104 Evaluation Board

The Xilinx ZCU104 evaluation board uses the mid-range ZU7 UltraScale+ device to enable you to jumpstart your machine learning applications. For more information on the ZCU104 board, refer to the Xilinx site https://www.xilinx.com/products/boards-and-kits/zcu104.html.

The main connectivity interfaces for ZCU104 are shown in the following figure.

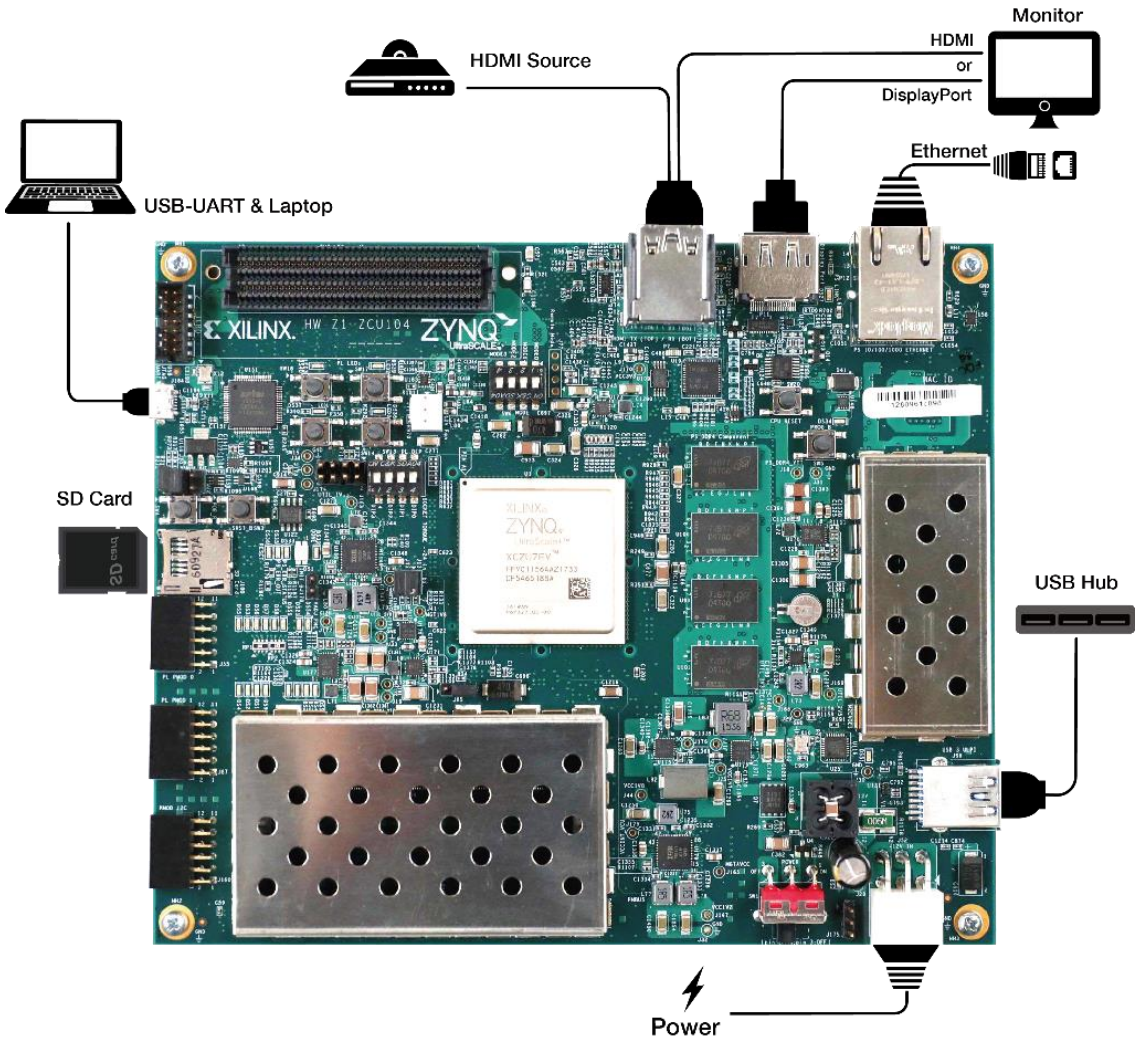


Figure 7: Xilinx ZCU104 Evaluation Board and Peripheral Connections

The DPU signature information is shown in the following figure. Dual DPU cores running at 325 MHz are implemented on the Xilinx ZU7 device.

```
root@xilinx-zcu104-2019_1:~$dexplorer -w
[DPU IP Spec]
IP  Timestamp           : 2019-07-23 18:00:00
DPU Core Count          : 2

[DPU Core Configuration List]
DPU Core                : #0
DPU Enabled             : Yes
DPU Arch                : B4096
DPU Target Version      : v1.4.0
DPU Freqency            : 325 MHz
Ram Usage               : High
DepthwiseConv           : Enabled
DepthwiseConv+Relu6     : Enabled
Conv+Leakyrelu          : Enabled
Conv+Relu6              : Enabled
Channel Augmentation    : Enabled
Average Pool            : Enabled

DPU Core                : #1
```

Figure 8: Xilinx ZCU104 DPU signature viewed with DExplorer

In the following sections, ZCU102 is used as an example to show the steps to setup the DNNDK running environment on evaluation boards.

Flash the OS Image to the SD Card

One suggested software application for flashing the SD card is Etcher. It is a cross-platform tool for flashing OS images to SD cards, available for Windows, Linux and Mac systems. The following example uses Windows.

1. Download Etcher from: https://etcher.io/ and save the file as shown in the following figure.

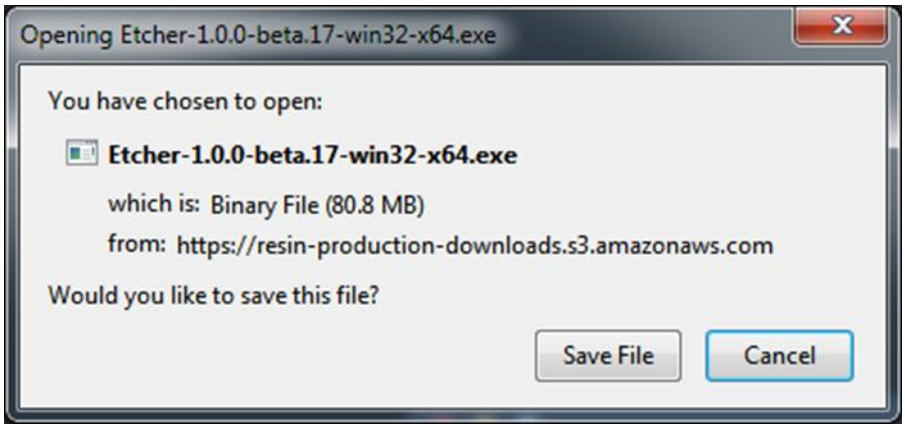


Figure 9: Saving the Etcher File

2. Install Etcher, as shown in the following figure.

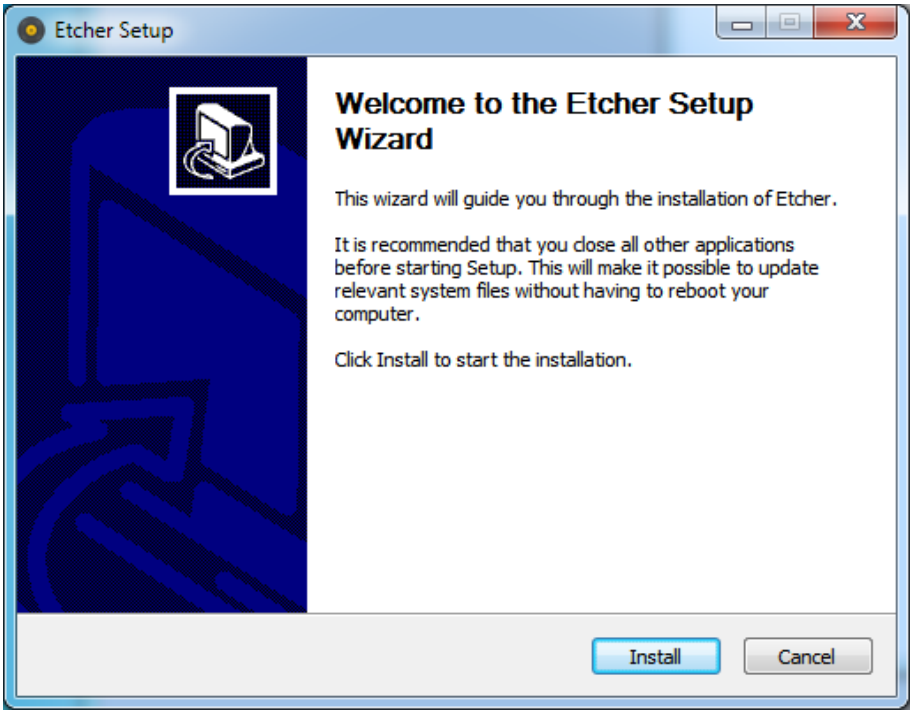


Figure 10: Install Etcher

3. Eject any external storage devices such as USB flash drives and backup hard disks. This makes it easier to identify the SD card. Then, insert the SD card into the slot on your computer, or into the reader.
4. Run the Etcher program by double clicking on the Etcher icon shown in the following figure, or select it from the **Start** menu.

Figure 11: Etcher Icon

Etcher launches, as shown in the following figure.

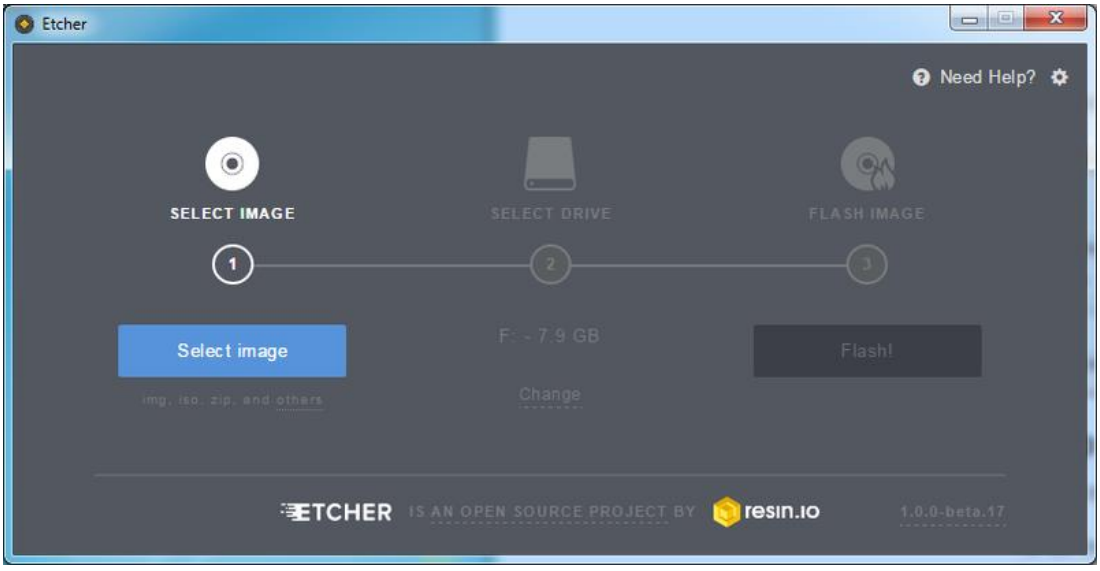


Figure 12: The Etcher Interface

5. Select the image file by clicking Select Image. You can select a .zip or .gz compressed file.
6. Etcher tries to detect the SD drive. Verify the drive designation and check the image size to make sure that it is correct.
7. Click **Flash**.

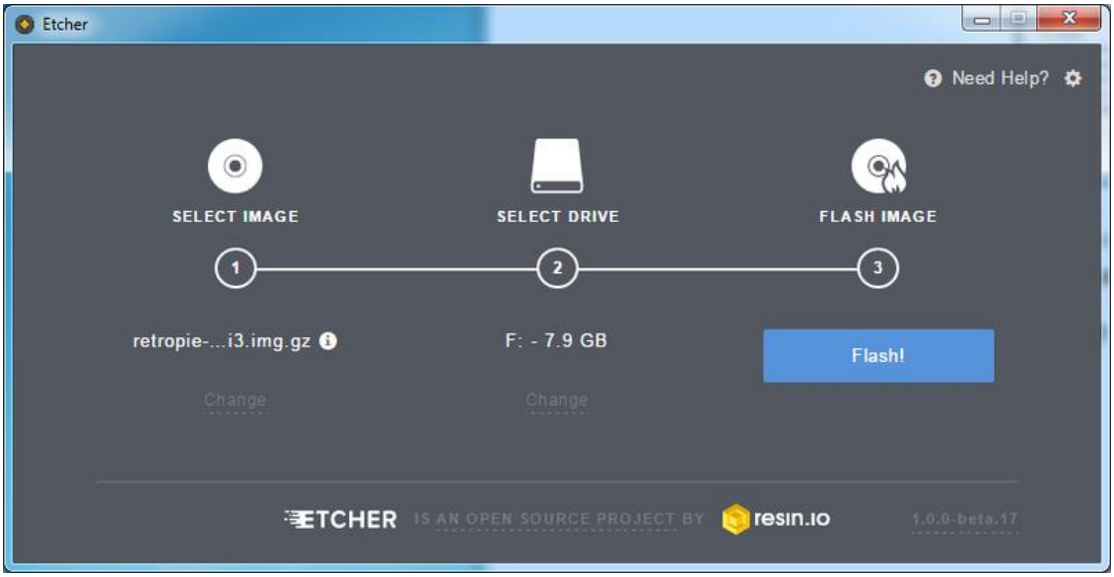


Figure 13: Flash the Card

Booting the Evaluation Board

In this section, a ZCU102 board is used to illustrate how to boot a DNNDK evaluation board. Follow the steps below to boot the evaluation board.

1. Connect the power supply (12V ~ 5A).

2. Connect the UART debug interface to the host and other peripherals as required.
3. Turn on the power, and wait for the system to boot.
4. Log into the system.
5. The system needs to perform some configurations for its first boot. Then reboot the board for these configurations to take effect.

Accessing the Evaluation Board

There are three ways to access the ZCU102 board: via UART, ethernet, or standalone.

Configuring UART

Aside from monitoring the boot process and viewing kernel messages for debugging, you can log into the board through the UART. The configuration parameters of the UART are shown below. A screenshot of a sample boot is shown in the following figure. Log into the system with username "root" and password "root".

- baud rate: 115200 bps
- data bit: 8
- stop bit: 1
- no parity

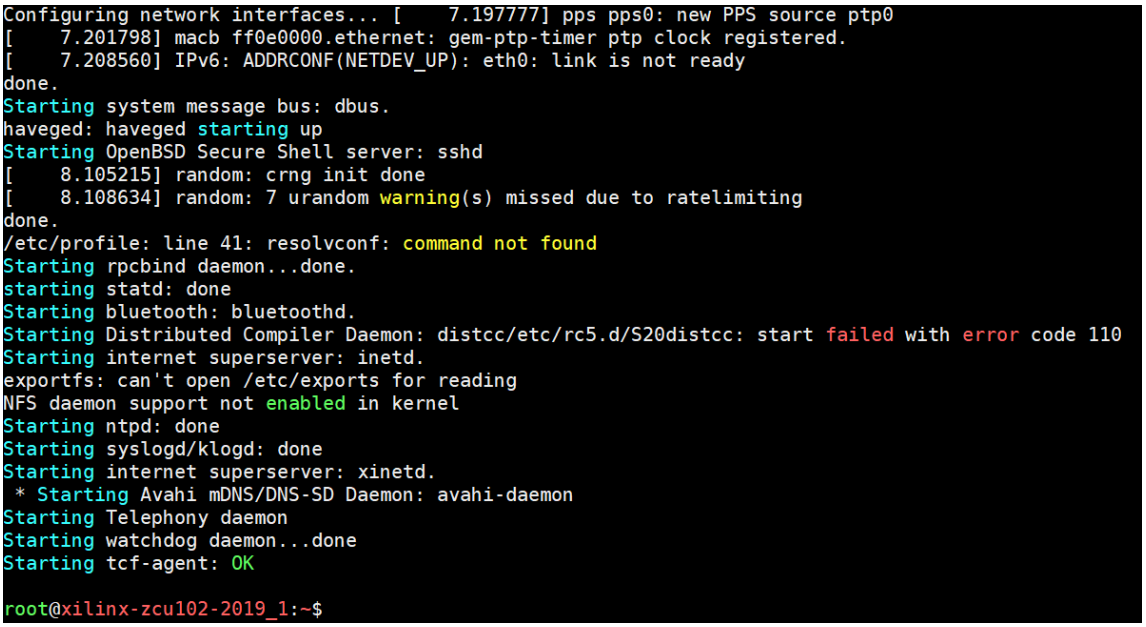


Figure 14: Example of Boot Process

Note: On a Linux system, you can use Minicom to connect to the target board directly; for a Windows system, a USB to UART driver is needed before connecting to the board through a serial port.

Using the Ethernet Interface

The ZCU102 board has an Ethernet interface, and SSH service is enabled by default. You can log into the system using an SSH client after the board has booted.

```
$ ssh root@10.10.138.5
The authenticity of host '10.10.138.5 (10.10.138.5)' can't be established.
ECDSA key fingerprint is SHA256:fhV82DTs+VPOjSrWR3DznA9LmQy2glwnguDY3khiOWM.
Are you sure you want to continue connecting (yes/no)? yes
Warning: Permanently added '10.10.138.5' (ECDSA) to the list of known hosts.
root@10.10.138.5's password:
Last login: Mon Jul 29 22:46:37 2019 from 10.10.21.160
root@xilinx-zcu102-2019_1:~$
```

Figure 15: Logging into the Evaluation Board Using SSH

Use the `ifconfig` command via the UART interface to set the IP address of the board, then use the SSH client to log into the system.

Using the ZCU102 as a Standalone Embedded System

The ZCU102 board allows a keyboard, mouse, and monitor to be connected. After a successful boot, a Linux GUI desktop is displayed. You can then access the board as a standalone embedded system.

Figure 16: Standalone Linux GUI Screen

Copying DNNDK Tools to the Evaluation Board

With an ethernet connection established, you can copy the DNNDK package from the host machine to the evaluation board.

The steps below illustrate how to setup DNNDK running environment for ZCU102 provided that DNNDK package is stored on a Windows system.

1. Download and install MobaXterm on Windows system. MobaXterm is a terminal for Windows, and is available online at https://mobaxterm.mobatek.net/.
2. Launch MobaXterm and click **Start local terminal** to open a terminal where the filesystem of Windows can be accessed.
3. Extract and copy the package for the board.

   For example, suppose that the DNNDK package is located under the root directory of disk `D`. In this case, use the following commands to extract and copy the package for the ZCU102 board with IP address 192.168.0.10:

   ```
   cd d:
   tar -xzvf xilinx_dnndk_v3.1_1908
   cd  xilinx_dnndk_v3.1_1908/
   scp -r ./ZCU102  root@192.168.0.10:~/
   ```

4. On the ZCU102 board, change to the *~/ZCU102/* directory and run *install.sh*. The following messages display if the installation completes successfully.

   ```
   Begin to install Xilinx DNNDK ...
   Install DPU driver ...
   Install tools, runtime & libraries ...
   Install python support ...
   Processing ./pkgs/python/dnndk-3.1-py2-none-any.whl
   Installing collected packages: dnndk
   Complete installation successfully.
   ```

Note: Installing DNNDK v3.1 will automatically replace previous releases. There is no need to manually uninstall previous versions.

Running DNNDK examples

This section will illustrate how to run each example included in the DNNDK package, using the Xilinx ZCU102 board as a reference.

All examples may be compiled and launched after successful installation of the DNNDK package. They are stored under the `$dnndk_pkg/ZCU102/samples` folder. In the subsequent sections, we will use the string "$dnndk_sample_base" to represent the folder name of `$dnndk_pkg/ZCU102`.

Make sure to enable X11 forwarding with the following command (supposed that host machine IP address is 192.168.0.10) when logging in to the board using an SSH terminal since all the examples require a Linux windows system to work properly.

```
export DISPLAY=192.168.0.10:0.0
```

For each DNNDK example, after entering into its directory, run the `make` command first to generate the hybrid DPU executable file, then launch it just like a normal Linux application.

Note1: The DNNDK examples won't work through a UART connection due to the lack of Linux windows.

Note2: The monitor flickers while running for some DNNDK examples because DPU demands heavy memory bandwidth.

ResNet-50

`$DNNDK_SAMPLE_BASE/samples/resnet50` contains an example of image classification using the ResNet-50 network. It reads the images under the `$dnndk_sample_base/samples/common` directory and outputs the classification result for each input image.

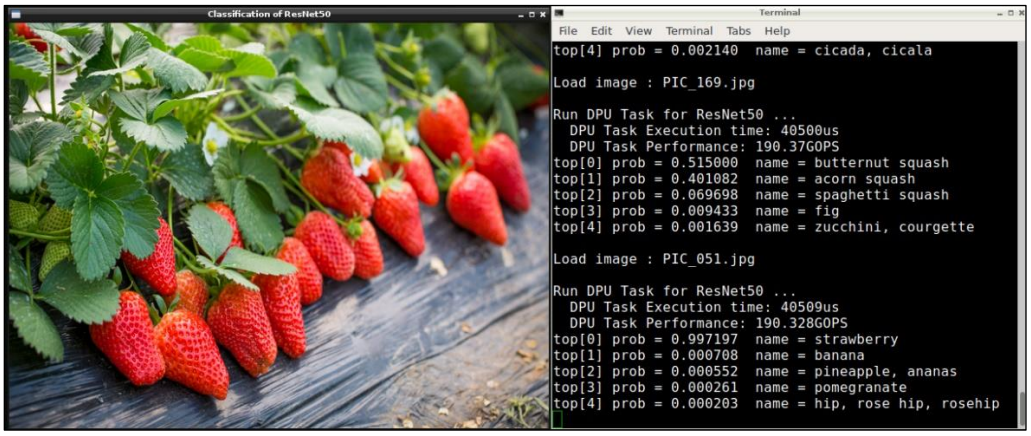


Figure 17: Screenshot of ResNet-50 example

After running `make` and launching it with the command `./resnet50`, the result is shown in Figure , including the top-5 labels and corresponding probabilities.

Video analytics

An object detection example is located under the "$dnndk_sample_base/samples/video_analysis" directory. It reads image frames from a video file and annotates detected vehicles and pedestrians in real-time. Run make and launch it with the command "./video_analysis video/structure.mp4" (where video/structure.mp4 is the input video file). A screenshot is shown in Figure .

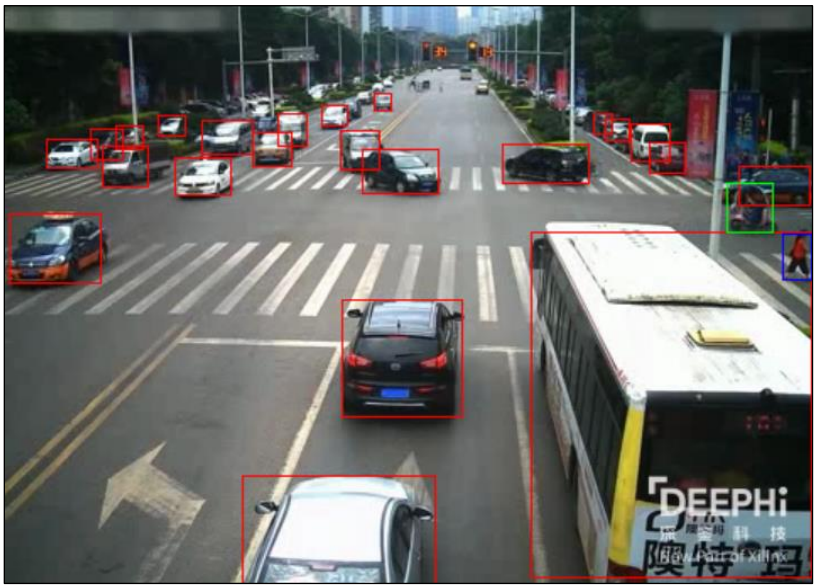


Figure 18: Screenshot of object detection example

ADAS detection

An example of object detection for ADAS (Advanced Driver Assistance Systems) application using YOLO-v3 network model is located under the "$dnndk_sample_base/samples/adas_detection" directory. It reads image frames from a video file and annotates in real-time. Run make and launch it with the command "./adas_detection video/adas.avi" (where video/adas.mp4 is the input video file). A screenshot is shown in Figure .

Figure 19: Screenshot of ADAS detection example

Semantic segmentation

An example of semantic segmentation in the "$dnndk_sample_base/samples/segmentation" directory. It reads image frames from a video file and annotates in real-time. Run make and launch it with the

command "./segmentation video/traffic.mp4" (where video/traffic.mp4 is the input video file). A screenshot is shown in Figure .

Figure 20: Screenshot of semantic segmentation example

Inception-v1 with Python

`$dnndk_sample_base/samples/inception_v1_mt` contains a multithreaded image classification example of Inception-v1 network developed with DNNDK Python APIs. With the command `python inception_v1_mt.py 4`, it will run with 4 threads. The throughput (in fps) will be reported after it completes.

Different from C++ DNNDK examples, Incpetion-v1 model is compiled to DPU ELF file first and then it is transformed into the DPU shared library `libdpumodelinception_v1.so` with the following command. `dpu_inception_v1_*.elf` means to include all DPU ELF files in case that Incpetion-v1 is compiled into several DPU kernels. Refer to DPU Shared Library for more details.

```
aarch64-linux-gnu-gcc -fPIC -shared \
   dpu_inception_v1_*.elf -o libdpumodelinception_v1.so
```

Note: The thread number for best throughput of multithread Incepion-v1 example varies among evaluation boards since the DPU computation power and core number are differently equipped. Use "dexplorer -w" to view DPU signature information for each evaluation board.

minResNet with Python

`$dnndk_sample_base/samples/mini_resnet` contains the image classification example of TensorFlow minResNet network developed with DNNDK Python APIs. With the command `python mini_resnet.py`, the results of top-5 labels and corresponding probabilities are displayed.

miniResNet is described in the second book `Practitioner Bundle` of the `Deep Learning for CV with Python` series. It is a customization of the original ResNet-50 model and is also well explained in the third book `ImageNet Bundle` from the same book's series.

Support

You can visit the DNNDK community forum on the Xilinx website https://forums.xilinx.com/t5/Deephi-DNNDK/bd-p/Deephi for topic discussions, knowledge sharing, FAQs, and requests for technical support.

Copyright

Some third-party source code is used in the Deep Neural Network Development Kit (DNNDK) toolchain. Refer to the file `$dnndk_pkg/COPYRIGHT` for the related copyright declaration.

Version

Host Package

The "host_x86" directory in the DNNDK release package contains the host side tools Deep Compression Tool (DECENT),DNNC, DLet and DDump. The version information is shown below.

If you encounter issues while using DECENT or DNNC or DLet or DDump, contact the DNNDK support team and provide the version information. You can find this information using the command `decent --version, dnnc --version, dlet --version and ddump --version`. For DNNDK v3.1 release, the version info for DNNC, DLet and DDump is listed below.

```
dnnc version v3.00
DPU Target : v1.4.0
Build Label: Aug 9 2019 13:19:12
Copyright @2019 Xilinx Inc. All Rights Reserved.
DLet version 1.0
Build Label: Aug 7 2019 18:07:26
Copyright @2019 Xilinx Inc. All Rights Reserved.
DDump version 1.0
Build Label: Aug 7 2019 18:35:50
```

Target Package

The package for the target Deep-learning Processor Unit (DPU) evaluation board contains several components: DExplorer, DSight, DDump, DPU driver, and runtime N^2Cube. The component versions for each evaluation board are shown below. If you encounter issues while running DNNDK applications on evaluation boards, contact the DNNDK support team and provide the version information. You can find this information using the command `dexplorer -v`.

ZedBoard Component Versions

```
DNNDK version  3.1
Copyright @ 2018-2019 Xilinx Inc. All Rights Reserved.
```

```
Explorer version 2.0
Build Label: Aug  7 2019 18:26:44

DSight version 1.4
Build Label: Aug  7 2019 18:26:44

DDump version 1.0
Build Label: Aug  7 2019 18:26:44

N2Cube Core library version 3.0
Build Label: Aug  7 2019 18:26:39

DPU Driver version 3.0.0
Build Label: Aug  7 2019 18:26:24
```

Ultra96 Component Versions

```
DNNDK version  3.1
Copyright @ 2018-2019 Xilinx Inc. All Rights Reserved.

DExplorer version 2.0
Build Label: Aug  7 2019 18:28:41

DSight version 1.4
Build Label: Aug  7 2019 18:28:42

DDump version 1.0
Build Label: Aug  7 2019 18:28:42

N2Cube Core library version 3.0
Build Label: Aug  7 2019 18:28:37

DPU Driver version 3.0.0
Build Label: Aug  7 2019 18:28:16
```

ZCU102 Component Versions

```
DNNDK version  3.1
Copyright @ 2018-2019 Xilinx Inc. All Rights Reserved.

DExplorer version 2.0
Build Label: Aug  7 2019 18:36:21

DSight version 1.4
Build Label: Aug  7 2019 18:36:21

DDump version 1.0
Build Label: Aug  7 2019 18:36:21

N2Cube Core library version 3.0
Build Label: Aug  7 2019 18:36:17

DPU Driver version 3.0.0
Build Label: Aug  7 2019 18:35:56
```

ZCU104 Component Versions

```
DNNDK version  3.1
Copyright @ 2018-2019 Xilinx Inc. All Rights Reserved.

DExplorer version 2.0
Build Label: Aug  7 2019 18:24:23

DSight version 1.4
Build Label: Aug  7 2019 18:24:23

DDump version 1.0
Build Label: Aug  7 2019 18:24:23

N2Cube Core library version 3.0
Build Label: Aug  7 2019 18:24:18

DPU Driver version 3.0.0
Build Label: Aug  7 2019 18:23:56
```

The key improvements and changes in each release of the Deep Neural Network Development Kit (DNNDK) toolchain since the first version 1.07 published in Oct. 2017 are summarized in this chapter. A guide is provided to allow you to port Deep-learning Processor Unit (DPU) applications from a previous DNNDK version to the latest version.

Since v3.1

The key feature and changes of DNNDK v3.1 release are summarized in this section for the users' quick overview.

DPU IP Changes

The configurable feature of DPU is formally enabled by DNNDK v3.1. Compared with DNNDK v3.0, the enhanced DPU v1.4.0 is released together with DNNDK v3.1 enabled evaluation boards. DPU is user-configurable and exposes several parameters which can be specified by the users to optimize PL resources or customize the enabled features. Please refer to DPU IP Product Guide (PG338) for more details.

Toolchain Changes

DECENT

DECENT supports Ubuntu 18.04 with CUDA 10.0 and cuDNN 7.4.1, and the supported TensorFlow version is upgraded from v1.9 to v1.12.

DNNC

The version DNNC is updated to v3.0, and it is unified to one single version binary applicable for any kinds of DPU configuration parameters. With the DPU configuration parameters provided by DLet, DNNC generates the suited DPU instruction code. Accordingly, the option `--dpu` is discarded, and instead a new option `--dcf` is introduced to support DNNC automated model compilation for configurable DPU.

In addition, DNNC is under continuously improvement to produce more high quality DPU code for diverse popular Caffe and TensorFlow models to better meet the users' requirements.

DLet

DLet is host tool designed to parse and extract various DPU configuration parameters from DPU Hardware Handoff file `HWH` generated by Vivado. It works together with DNNC to support model

compilation under various DPU configurations. Also, the DPU IP used in the Vivado project should come from Edge AI Targeted Reference Designs (DPU TRD) v3.0 or higher version.

DDump

DDump is a new utility tool introduced to dump the info encapsulated inside DPU ELF file or hybrid executable or DPU shared library by DNNC compiler. It can facilitate the users to analyze and debug various issues. It is available for both Linux host and DNNDK evaluation boards.

API Changes

DNNDK begins to support Python programming APIs, which are kept almost identical with C++ interface to make them easily used. The sample of multithreading Inception-v1 in release package demonstrates the usage of Python APIs.

Example Changes

Several DNNDK samples for various evaluation boards are added in this release to illustrate how to deploy network models with DNNDK C++ or Python programming APIs. Please refer to the sample code for details.

Since v3.0

The most important feature of DNNDK v3.0 is that popular deep learning framework TensorFlow is officially supported by DNNDK toolchains.

DeePhi DP-N1 AI Box and DP-8020 are removed from the evaluation board list enabled by DNNDK since this release.

Toolchain Changes

DECENT

TensorFlow framework is supported by DECENT. And since DNNDK v3.0, both CPU version and GPU version DECENT binary tools are released for user convenience. CPU version DECENT can perform quantization on CPU-only host machine without GPU installed; however, this requires longer running time.

Added support for fully-grouped deconvolution and GSTiling layers for Caffe version.

Added support for un-matched caffemodel and prototxt for Caffe version.

Removed dependency for YAML and used protobuf file for `-ignore_nodes_file` option for Caffe version.

DNNC

Caffe and TensorFlow are supported by one single DNNC binary tool. For TensorFlow, it is enabled by the new introduced options `--parser` and `--frozen_pb`. Refer to Using DNNC for details.

Example Changes

All samples are removed from DNNDK release package. For more reference, download the Xilinx® AI SDK.

Since v2.08

Two new evaluation boards DeePhi DP-N1 AI Box and Ultra96 have been enabled since the v2.08 release. With the existing three boards DP-8020, ZCU102, and ZCU104, there are now a total of five evaluation boards available. Meanwhile, DNNDK toolchains are under the continuous enhancements to improve performance of the DPU, to make tools easy to use, to make DNNDK more suitable for production environment, and so on.

Toolchain Changes

DECENT

The dependency of Nvidia NCCL library is removed from Deep Compression Tool (DECENT). There is no longer a need to install NCCL on an x86 host machine. DECENT supports an X86 host machine without GPU.

DNNC

The new option `--abi` was introduced since DNNC v2.03 for the purpose of DNNDK forward compatibility. Refer to Using DNNC for a detailed description.

Exception Handling Changes

A new exception handling mode for N^{2}Cube runtime APIs is introduced. For the former releases, N^{2}Cube will output the error message and terminate the running of DNNDK application when any error occurs.

Since v2.08, N2Cube runtime APIs will return corresponding error code and will not exit in case of errors. The API callers must take charge of the following exception handling process, such as logging the error message with API `dpuGetExceptionMessage()`, resource release, and so on.

To keep forward compatibility, the former exception handling manner is the default mode, but it can be changed to new mode using `dpuSetExceptionMode()`.

API Changes

The following four new APIs were introduced into the libn2cube library. Refer to Chapter 13: Python Programming APIs for details.

- `dpuRunSoftmax()`
- `dpuSetExceptionMode()`
- `dpuGetExceptionMode()`
- `dpuGetExceptionMessage()`

Example Changes

Three new DNNDK examples were added to demonstrate the DPU capabilities and scalabilities, including:

- MobileNet
- Multithreaded MobileNet
- ADAS detection with YOLO-v3 network model

Since v2.07

Only one evaluation board was supported in previous releases. Beginning with the 2.07 release, the supported evaluation boards are DP-8020, ZCU102, and ZCU104.

Toolchain Changes

DNNC

The following minor updates were made to DNNC to improve its ease of use.

1. The kernel graph description file `<net_name>_kernel_graph.jpg` in JPEG format is generated by DNNC if the host system has the `dot` command installed; otherwise, the original `gv` format file with the same name is generated.
2. Instead of simply printing the input/output node name for DPUKernel in the kernel description, the input/output index for node name is also added in `node_name(index)` format. When setting input or getting output using the API provided by N^{2}Cube, the `node_name` and `index` act as unique identifiers.
3. A `dump` option has been added to DNNC for error probing (see Chapter 7: Network Compilation for more details).

Since v2.06

Toolchain Changes

DECENT

- Added more operators:
  - Dilation convolution
  - Deconvolution
  - Flatten
  - Concat
  - Scale
  - Reorg
- Added more layer fusing patterns:
  - Fuse BatchNorm + Scale + Convolution into Convolution layer
  - Fuse standalone BatchNorm + Scale into Scale layer
- Added support for TensorFlow framework (for DeePhi internal evaluation only)
- Other minor changes:
  - Support auto test for cityscapes segmentation dataset
  - Support for CV_16U image input

DNNC

- Added more operators:
  - Dilation convolution
  - Deconvolution
  - Flatten
  - Concat
  - Scale
  - Reorg
- Implement more optimizing compilation techniques:
  - Add more flexible node fusion strategies
  - Perform adaptive optimizations for concat and flatten operators
- Added support for TensorFlow framework (for Xilinx internal evaluation only)
- Support for DPU ABI v1.7

DExplorer

DExplorer is updated with the new option "-w" to display the DPU signature information, such as DPU architecture version, target version, working frequency, DPU core numbers, and so on.

Changes in API

Multiple IO is supported in this release. Therefore, all the API around input/output tensor such as `dpuGetInputXX/dpuGetOutputXX/dpuSetInputXX/dpuSetOutputXX` have been changed to preserve backward compatibility.

If multiple IO is not required in your application, no change is required.

Otherwise, pass an `idx` to specify a single tensor as the last parameter to the APIs, and refer to the `kernel_graph.gv` file generated by DNNC to get the value of `idx`.

New APIs: `dpuGetInputTensorCnt/ dpuGetOutputTensorCnt` are available to get the total number of input/output tensors for this node.

Example Changes

VGG-16 has been removed in this release due to its large size. New examples have been introduced, including:

- Multithreaded ResNet-50
- Multithreaded Inception-v1
- Semantic segmentation
- Pose estimation

Since v1.10

Toolchain Changes

DECENT

When performing neural network model compression, DECENT will incorporate the fix info into the compressed Caffe model file, instead of generating a separate file `fix_info.txt`. The DNNC compiler will deal with the fix information automatically.

The mean value was encapsulated into the prototxt file during model compression. The DNNC compiler handles this automatically.

Note: Use the DECENT and DNNC version included in the DNNDK release when compressing and compiling network models to avoid unexpected errors.

DNNC

Automatic CPU and DPU mapping.

- DNNC compiler optimization for multiplexed memory access.
- One-click compilation support for more neural networks including ResNet-50, VGG-16, Inception, SSD, YOLO, SqueezeNet, and DenseBox.
- Bug fixes, more hints, and error checking for handling user input.

DExplorer

The DExplorer utility has been added into this release, which can be used to show the DNNDK component version and DPU information.

DSight

The DSight utility is a performance profiling tool that has been added to this release.

Changes in API

New API

`dpuSetInputImage2()` – set input image to DPU Task, bypassing the requirement to specify the mean value parameter. Note the difference between this and the `dpuSetInputImage()` API.

Changed API

`dpuEnableTaskDebug()` has been renamed to `dpuEnableTaskDump()`.

Upgrading from Previous Versions

From v1.10 to v2.06

In this section, upgrading a deep learning application deployed with DNNDK v1.10 to DNNDK v2.06 using ResNet-50 is shown as an example.

1. Recompress the network model using DECENT from DNNDK v2.06 to generate new `deploy.prototxt` and `deploy.caffemodel` files.
2. Recompile the network model to generate ELF files for the new DPU kernel. Note that there is a change in the output file in v2.06. A new file named `kernel_graph.gv` will be generated by DNNC, which shows the structure of the network. It can be converted to JPEG format using a `dot` command (such as `dot -Tjpg -o xxx.jpg kernel_graph.gv`).

3. The `kernel_graph.gv` shows the input and output tensors at each node. Use `dpuGetOutputTensorCnt()` or `dpuGetInputTensorCnt()` to get the number of tensors at a node, and use an extra parameter `idx` to specify the tensor in subsequent processing functions. The `idx` is the index (beginning with 0, from left to right in `x.jpg`) of the tensor for a node. No changes are needed for the deployed code if the network has not changed.

From v1.07 to v1.10

In this section, upgrading a deep learning application deployed with DNNDK v1.07 to DNNDK v1.10 using ResNet-50 is shown as an example.

1. Recompress the network model using DECENT from DNNDK v1.10 to generate new `deploy.prototxt` and `deploy.caffemodel` files.
2. Recompile the network model to generate ELF files for the new DPU kernel. Note that the suffix "`_fixed`" has been removed in the generated files. For example, if the network is compiled with the option `–net_name=resnet50`, v1.07 would have generated `dpu_resnet50_fixed.elf` and `dpu_reset50_fc_fixed.elf`. In v1.10, the generated files will be named `dpu_resnet50_0.elf` and `dpu_resnet50_2.elf`. Make sure that the source code is modified to load the proper DPU kernel file when calling `dpuLoadKernel()`.
3. Modify `Makefile` to change the DPU kernel ELF file name from `dpu_resnet50_fixed.elf` and `dpu_resnet50_fc_fixed.elf` to `dpu_resnet50_0.elf" and "dpu_resnet50_2.elf`.
4. Consider using the new simplified API dpuSetInputImage2() instead of dpuSetInputImage().

Overview

Deep Neural Network Development Kit (DNNDK) is a full-stack deep learning SDK for the Deep-learning Processor Unit (DPU). It provides a unified solution for deep neural network inference applications by providing pruning, quantization, compilation, optimization, and run time support. Key highlights and features are listed below:

Innovative full-stack solution for deep learning inference application development

- A complete set of optimized tool chains, including compression, compilation and runtime.
- Lightweight C/C++ and Python programming APIs.
- Easy-to-use with gradual learning curve.

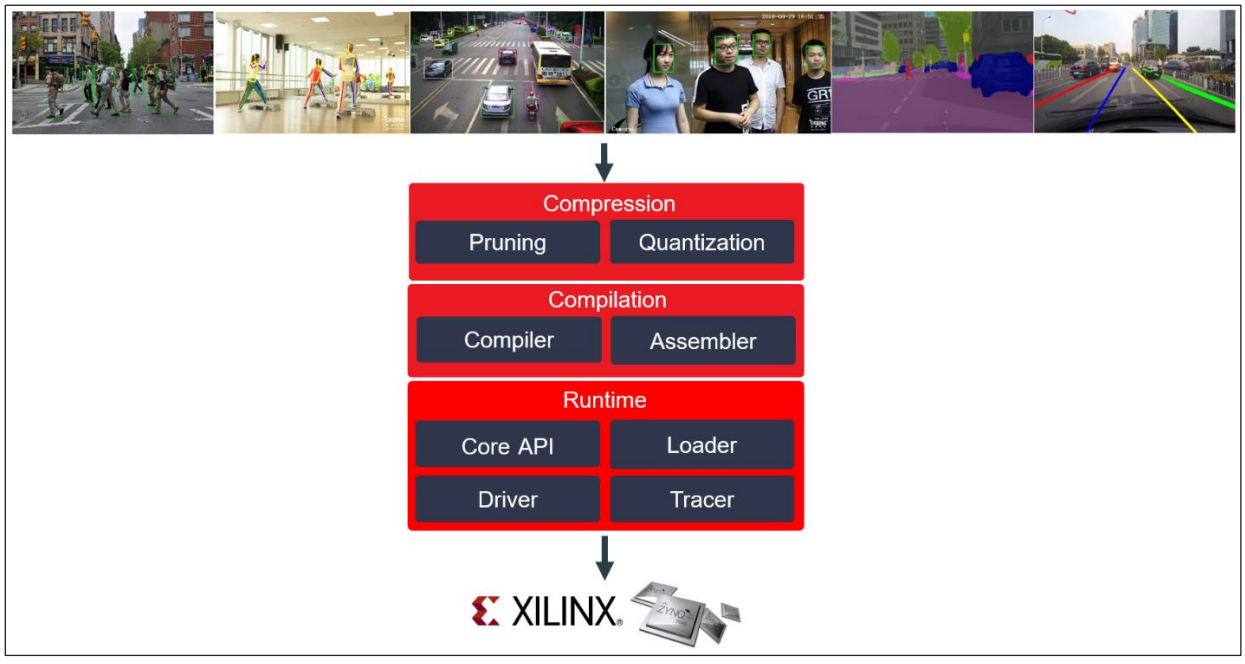


Figure 21: DNNDK Framework

DNNDK makes it simple for users without FPGA knowledge to develop deep learning inference applications by providing a set of lightweight C/C++ APIs while abstracting away the intricacies of the underlying FPGA device.

Deep-learning Processor Unit

The Xilinx® Deep learning Processor Unit (DPU) is designed to accelerate the computing workloads of deep learning inference algorithms widely adopted in various computer vision applications, such as image/video classification, semantic segmentation, and object detection/tracking.

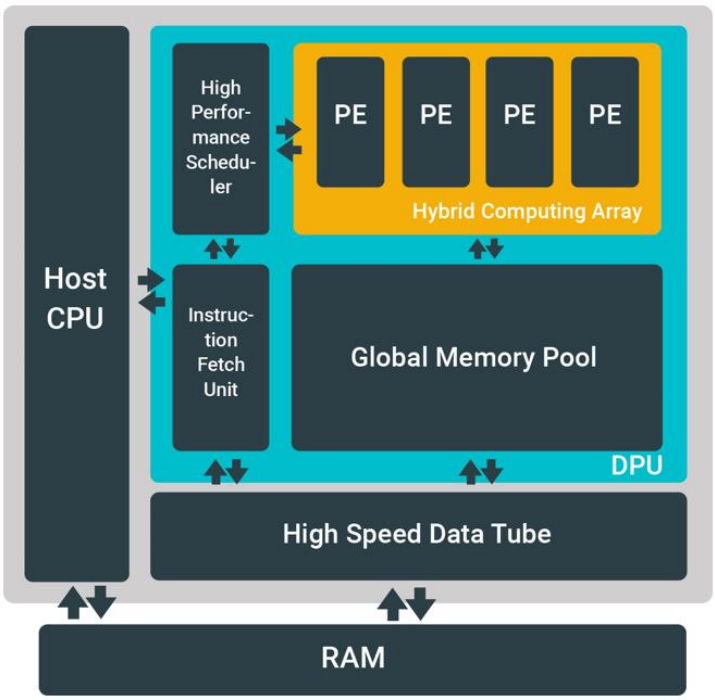


Figure 22: DPU Architecture

An efficient tensor-level instruction set is designed to support and accelerate various popular convolutional neural networks, such as VGG, ResNet, GoogLeNet, YOLO, SSD, and MobileNet, among others. The DPU is scalable to fit various Xilinx® Zynq®-7000 and Zynq UltraScale+™ MPSoC devices from edge to cloud to meet the requirements of many diverse applications.

The DPU IP can be integrated as a block in the programmable logic (PL) of the selected Zynq®-7000 SoC and Zynq UltraScale™+ MPSoC devices with direct connections to the processing system (PS). The configurable version DPU IP v1.4.0 is released together with DNNDK v3.1. DPU is user-configurable and exposes several parameters which can be specified by the users to optimize PL resources or customize the enabled features. Please refer to DPU IP Product Guide (PG338) for more details.

DNNDK Framework

As shown in the figure below, DNNDK framework is composed of Deep Compression Tool (DECENT), Deep Neural Network Compiler (DNNC), Deep Neural Network Assembler (DNNAS), Neural Network Runtime (N^2Cube), DPU Simulator, Profiler, DExplorer and DDump.

Since v3.0, DNNDK supports both Caffe and TensorFlow with a unified framework. The toolchain flow for deploying Caffe and TensorFlow network models are almost the same, which delivers a familiar user experience.

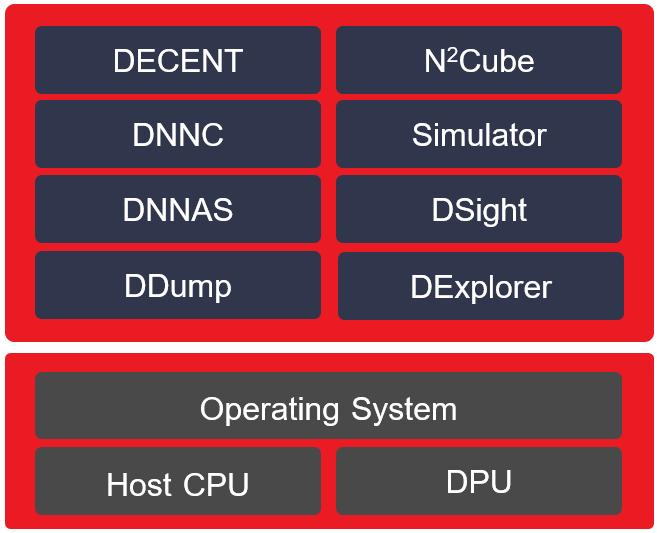


Figure 23: DNNDK Toolchain

NOTE: The DECENT tool can perform both model pruning and quantization; however, only quantization functionality is included in this release package.

DECENT

The process of inference is computation intensive and requires a high memory bandwidth to satisfy the low latency and high throughput requirement of edge applications.

The Deep Compression Tool, DECENT™, employs coarse-grained pruning, trained quantization and weight sharing to address these issues while achieving high performance and high energy efficiency with very small accuracy degradation.

DNNC

DNNC™ (Deep Neural Network Compiler) is the dedicated proprietary compiler designed for the DPU. It maps the neural network algorithm to the DPU instructions to achieve maxim utilization of DPU resources by balancing computing workload and memory access.

N2Cube

The Cube of Neutral Networks (N^2Cube) is the DPU runtime engine. It acts as the loader for the DNNDK applications and handles resource allocation and DPU scheduling. Its core components include DPU driver, DPU loader, tracer, and programming APIs for application development.

N^2Cube provides a lightweight set of programming interfaces through a library which abstracts away the details of the underlying hardware implementation.

The DPU driver runs in the kernel space of the Linux OS and includes DPU functions such as task scheduling, and efficient memory management to avoid memory copy overhead between the DPU and the CPU.

The DPU loader is responsible for dynamically loading DPU code and data into the DPU dedicated memory space and performs runtime address relocation.

The DPU performance profiler makes it possible for programmers to analyze the efficiency of DPU code and the utilization of resources layer by layer.

DNNAS

The Deep Neural Network Assembler (DNNAS) is responsible for assembling DPU instructions into ELF binary code. It is a part of the DNNC code generating back end, and cannot be invoked alone.

Profiler

The DPU profiler is composed of two components: DPU tracer and DSight. DPU tracer is implemented in the DNNDK runtime N^2cube, and it is responsible for gathering the raw profiling data while running neural networks on DPU. With the provided raw profiling data, DSight can help to generate the visualized charts for performance analysis.

DDexplorer

DExplorer is a utility running on DNNDK evaluation board. It provides DPU running mode configuration, DNNDK component version checking, DPU status checking, and DPU core signature checking.

DDump

DDump is a utility tool to dump the info encapsulated inside DPU ELF file or hybrid executable or DPU shared library. It can facilitate the users to analyze and debug various issues. DDump is available for both x86 Linux host and DNNDK evaluation boards.

Overview

There are two stages for developing deep learning applications: training and inference. The training stage is used to design a neural network for a specific task (such as image classification) using a huge amount of training data. The inference stage involves the deployment of the previously designed neural network to handle new input data not seen during the training stage.

The DNNDK toolchain provides an innovative workflow to efficiently deploy deep learning inference applications on the DPU with five simple steps:

1. Compress the neural network model.
2. Compile the neural network model.
3. Program with DNNDK APIs.
4. Compile the hybrid DPU application.
5. Run the hybrid DPU executable.

In this chapter, ResNet-50 is used as an example to walk through each step. The Caffe/TensorFlow floating-point models for Resnet-50 and Inception-v1 can be found from DNNDK package as shown in the following table.

Table 2: Neural Network Models in the DNNDK package

Model	Directory
ResNet-50	$dnndk_pkg/host_x86/models/caffe/resnet50 $dnndk_pkg/host_x86/models/tensorflow/resnet50
Inception-v1	$dnndk_pkg/host_x86/models/caffe/inception_v1 $dnndk_pkg/host_x86/models/tensorflow/inception_v1

Note: This chapter only covers model quantization with the Deep Compression Tool (DECENT) because the pruning tool is not included in this release.

Network Compression (Caffe Version)

DECENT takes a floating-point network model, pre-trained weights and a calibration dataset in Caffe format as inputs to generate a lightweight quantized model with INT8 weights.

Table 3: DECENT Input Files

No.	Name	Description
1	float.prototxt	Floating-point model for ResNet-50. The data layer in the prototxt should be consistent with the path of calibration dataset.
2	float.caffemodel	Pre-trained weights file for ResNet-50
3	calibration dataset	A subset of the training set containing 100 to 1000 images

A script file named `decent.sh` is located in `$dnndk_pkg/host_x86/models/resnet50`, shown in the following figure. This invokes the DECENT tool to perform quantization with the appropriate parameters.

```
#working directory
work_dir=$(pwd)
#path of float model
model_dir=${work_dir}
#output directory
output_dir=${work_dir}/decent_output

[ -d "$output_dir" ] || mkdir "$output_dir"

decent     quantize                                  \
           -model ${model_dir}/float.prototxt        \
           -weights ${model_dir}/float.caffemodel    \
           -output_dir ${output_dir}                 \
           -method 1
```

Figure 24: Sample DECENT Quantization Script

Note: Before launching quantization for ResNet-50, you should first prepare the calibration data set used by DECENT. You can download 100 to 1000 images of ImageNet data set from http://academictorrents.com/collection/imagenet-2012 or http://www.image-net.org/download.php and then change the settings for `source` and `root_folder` of `image_data_param` in ResNet-50 prototxt accordingly.

The script might take several minutes to an hour to finish. Once quantization is done, the files `deploy.prototxt` and `deploy.caffemodel` are generated in the `decent_output` directory, which could be fed to DNNC compiler for following compilation process.

Table 4: DECENT Output Files

N0.	Name	Description

1	deploy.prototxt	quantized network description file
2	deploy.caffemodel	quantized Caffe model parameter file (non-standard Caffe format)

Network Compression (TensorFlow Version)

Step 1: Prepare floating-point frozen model and dataset

Table 5: Input files for DECENT_Q

No.	Name	description
1	Frozen_graph	Located in ${DNNDK}/ host_x86/models/tensorflow/resnet_v1_50
2	calib_images	Before launching quantization for ResNet-50, you should first prepare the calibration data set used by DECENT. You can download 100 to 1000 images of ImageNet data set from http://academictorrents.com/collection/imagenet-2012 or http://www.image-net.org/download.php and then change the calibration dataset path in the input_fn
3	input_fn	A python function to read images in calibration dataset and do preprocess, locates in ${DNNDK}/ host_x86/models/tensorflow/resnet_v1_50

"resnet_v1_50_input_fn.py" is shown as below. As the image preprocessing is not included in the frozen graph, so we do it in the input_fn. As we can see, central_crop and means_subtraction are done for resnet_v1_50 image preprocessing.

```
calib_image_dir = "../../calibration_data/images/"
calib_image_list = "../../calibration_data/calib.txt"
calib_batch_size = 50
def calib_input(iter):
  images = []
  line = open(calib_image_list).readlines()
  for index in range(0, calib_batch_size):
    curline = line[iter * calib_batch_size + index]
    calib_image_name = curline.strip()
    image = cv2.imread(calib_image_dir + calib_image_name)
    image = central_crop(image, 224, 224)
    image = mean_image_subtraction(image, MEANS)
    images.append(image)
  return {"input": images}
```

Step 2: Run DECENT_Q

A script file named "decen_q.sh" can be found in *${DNNDK}/ host_x86/models/tensorflow/resnet_v1_50/*, shown as below. Run "**sh decent_q.sh**" to invoke the DECENT_Q tool to perform quantization with the appropriate parameters.

```
decent_q quantize \
  --input_frozen_graph frozen_resnet_v1_50.pb \
  --input_nodes input \
  --input_shapes ?,224,224,3 \
  --output_nodes resnet_v1_50/predictions/Reshape_1 \
  --input_fn resnet_v1_50_input_fn.calib_input \
  --method 1 \
  --gpu 0 \
  --calib_iter 10 \
  --output_dir ./quantize_results \
```

The script may take several minutes to finish. Once quantization is done, the quantization summary will be displayed as below:

```
INFO: Done Calibration
INFO: Start Generate Deploy Model
INFO: End Generate Deploy Model
********************* Quantization Summary *********************
INFO: Output:
  quantize_eval_model: ./quantize_results/quantize_eval_model.pb
  deploy_model: ./quantize_results/deploy_model.pb
```

Two files as shown in Table will be generated under the *${DNNDK}/ host_x86/models/tensorflow/resnet_v1_50/quantize_results* directory. Then you could use the deploy_model.pb to compile the model using DNNC compiler and deploy it on DPU.

Table 6: DECENT_Q output files

No.	Name	Description
1	deploy_model.pb	Quantized model for DNNC (extended Tensorflow format)
2	quantize_eval_model.pb	Quantized model for evaluation and dump

Step 3: Evaluate the quantized model

Two script files named “evaluate_frozen_graph.sh” and “evaluate_quantized_graph.sh” can be found in ${DNNDK}/ host_x86/models/tensorflow/resnet_v1_50. They are used to perform evaluation for the float and quantized model respectively. **As the validation dataset is too large to be included in the installation package, please set the path to the validation dataset before you run these scripts.**

```
# Please set your imagenet validation dataset path here,
IMAGE_DIR=/home/shengxiao/dataset/imagenet_image/val_resize_256/
IMAGE_LIST=/home/shengxiao/dataset/imagenet_image/val.txt

# Please set your batch size settings here, #IMAGES = VAL_BATCHES * BATCH_SIZE
# Commonly there are 5w image in total for imagenet validation dataset
EVAL_BATCHES=1000
BATCH_SIZE=50

python resnet_v1_50_eval.py \
  --input_frozen_graph quantize_results/quantize_eval_model.pb \
  --input_node input \
  --output_node resnet_v1_50/predictions/Reshape_1 \
  --eval_batches $EVAL_BATCHES \
  --batch_size $BATCH_SIZE \
  --eval_image_dir $IMAGE_DIR \
  --eval_image_list $IMAGE_LIST \
  --gpu 0
```

The script may take several minutes to finish. Once evaluation is done, the accuracy of the models will be displayed as below:

```
Start Evaluation for 1000 Batches...
100% (1000 of 1000) |##################################################| Elapsed Time: 0:03:21 Time:  0:03:21
Accuracy: Top1: 0.6881000045239926, Top5: 0.8877199957966805
```

Network Compilation

DNNC can support both Caffe and TensorFlow model compilation in one binary tool. DNNDK provides different dnnc.sh script files for compiling Caffe ResNet-50 and TensorFlow ResNet-50 models. Running the script file invokes the DNNC tool to perform model compilation with the appropriate options.

Compiling Caffe ResNet-50

The script file for compiling Caffe ResNet-50 of ZCU102 board, `dnnc_ZCU102.sh`, can be found in `$dnndk_pkg/host_x86/models/caffe/resnet50`, as shown in the following figure. For Caffe model compilation, you can use the DNNC default parser; there is no need to specify parser type using the `--parser` option.

```
#!/usr/bin/env bash

net="resnet50"
CPU_ARCH="arm64"
DNNC_MODE="debug"
dnndk_board="ZCU102"
dnndk_dcf="../../../dcf/ZCU102.dcf"

model_dir="decent_output"
output_dir="dnnc_output"

if [ ! -d "$model_dir" ]; then
    echo "Can not found directory of $model_dir"
    exit 1
fi

[ -d "$output_dir" ] || mkdir "$output_dir"

echo "Compiling Network ${net}"
dnnc    --prototxt=${model_dir}/deploy.prototxt      \
        --caffemodel=${model_dir}/deploy.caffemodel \
        --output_dir=${output_dir}                   \
        --net_name=${net}                            \
        --dcf=${dnndk_dcf}                           \
        --mode=${DNNC_MODE}                          \
        --cpu_arch=${CPU_ARCH}
```

Figure 25: DNNC Compilation Script for Caffe ResNet-50

The following figure shows DNNC output information when compilation is successful.

```
Compiling network: resnet50
[DNNC][Warning] layer [prob] (type: Softmax) is not supported in DPU, deploy it in CPU instead.

DNNC Kernel topology "resnet50_kernel_graph.jpg" for network "resnet50"
DNNC kernel list info for network "resnet50"
                               Kernel ID : Name
                                       0 : resnet50_0
                                       1 : resnet50_1

                             Kernel Name : resnet50_0
--------------------------------------------------------------------------------
                             Kernel Type : DPUKernel
                               Code Size : 1.28MB
                              Param Size : 24.35MB
                            Workload MACs : 3262.50MOPS
                          IO Memory Space : 2.25MB
                               Mean Value : 104, 107, 123,
                               Node Count : 55
                              Tensor Count : 56
                     Input Node(s)(H*W*C)
                                 conv1(0) : 224*224*3
                    Output Node(s)(H*W*C)
                              fc1000(0) : 1*1*1000


                             Kernel Name : resnet50_1
--------------------------------------------------------------------------------
                             Kernel Type : CPUKernel
                     Input Node(s)(H*W*C)
                                   prob : 1*1*1000
                    Output Node(s)(H*W*C)
                                   prob : 1*1*1000
```

Figure 26: DNNC Compilation Log for Caffe ResNet-50

Compiling TensorFlow ResNet-50

The script file for compiling TensorFlow ResNet-50 model, `dnnc.sh`, can be found in `$dnndk_pkg/host_x86/models/tensorflow/resnet50`, as shown in the following figure. For TensorFlow model compilation, you must specify the parser type using `tensorflow` through the `--parser` option; otherwise DNNC will display an error.

```
#!/usr/bin/env bash

net="resnet_v1_50"
CPU_ARCH="arm64"
DNNC_MODE="debug"
dnndk_board="ZCU102"
dnndk_dcf="../../../dcf/ZCU102.dcf"

# Work space directory
work_dir=$(pwd)
# Path of caffe quantization model
model_dir=${work_dir}/quantize_results
# Output directory
output_dir="dnnc_output"
tf_model=${model_dir}/deploy_model.pb

if [ ! -d "$model_dir" ]; then
    echo "Can not found directory of $model_dir"
    exit 1
fi

[ -d "$output_dir" ] || mkdir "$output_dir"

echo "Compiling Network ${net}"
dnnc    --parser=tensorflow                     \
        --frozen_pb=${tf_model}                 \
        --output_dir=${output_dir}              \
        --dcf=${dnndk_dcf}                      \
        --mode=${DNNC_MODE}                     \
        --cpu_arch=${CPU_ARCH}                  \
        --net_name=${net}
```

Figure 27: DNNC Compilation Script for TensorFlow ResNet-50

The following figure shows DNNC output information when compilation is successful.

```
Compiling network: resnet50_tf
[DNNC][Warning] layer [resnet_v1_50_SpatialSqueeze] (type: Squeeze) is not supported in DPU, deploy it in CPU instead.
[DNNC][Warning] layer [resnet_v1_50_predictions_Softmax] (type: Softmax) is not supported in DPU, deploy it in CPU instead.

DNNC Kernel topology "resnet50_tf_kernel_graph.jpg" for network "resnet50_tf"
DNNC kernel list info for network "resnet50_tf"
                               Kernel ID : Name
                                       0 : resnet50_tf_0
                                       1 : resnet50_tf_1

                            Kernel Name : resnet50_tf_0
--------------------------------------------------------------------------------
                            Kernel Type : DPUKernel
                              Code Size : 1.08MB
                             Param Size : 24.35MB
                          Workload MACs : 2545.88MOPS
                        IO Memory Space : 2.25MB
                             Mean Value : 0, 0, 0,
                             Node Count : 58
                           Tensor Count : 59
                    Input Node(s)(H*W*C)
             resnet_v1_50_conv1_Conv2D(0) : 224*224*3
                   Output Node(s)(H*W*C)
            resnet_v1_50_logits_Conv2D(0) : 1*1*1000


                            Kernel Name : resnet50_tf_1
--------------------------------------------------------------------------------
                            Kernel Type : CPUKernel
                    Input Node(s)(H*W*C)
              resnet_v1_50_SpatialSqueeze : 1*1*1000
                   Output Node(s)(H*W*C)
         resnet_v1_50_predictions_Softmax : 1*1*1000
```

Figure 28: DNNC Compilation Log for TensorFlow ResNet-50

Output Kernels

For both Caffe and TensorFlow, DNNC compiles the ResNet-50 model into one DPU kernel, which is an ELF format file containing DPU instructions and parameters for ResNet-50. This also shows the information about layers unsupported by the DPU, as shown in figure 26on page 47, and Figure 28, on page 49 . The ResNet-50 network model is compiled and transformed into two different kernels:

- Kernel 0： resnet50_0 （run on DPU）
- Kernel 1： resnet50_1 （deploy on the CPU）

The kernels resnet50_0 runs on the DPU. DNNC generates an ELF object file for this kernel in the output_dir directory, with the name dpu_resnet50_0.elf.

The other kernel, resnet50_1, is for “Softmax” operations, which are not supported by DPU and must be deployed and run on the CPU.

```
Compiling network: resnet50
[DNNC][Warning] layer [prob] (type: Softmax) is not supported in DPU, deploy it in CPU instead.

DNNC Kernel topology "resnet50_kernel_graph.jpg" for network "resnet50"
DNNC kernel list info for network "resnet50"
                               Kernel ID : Name
                                       0 : resnet50_0
                                       1 : resnet50_1

                             Kernel Name : resnet50_0
--------------------------------------------------------------------------------
                             Kernel Type : DPUKernel
                               Code Size : 1.28MB
                              Param Size : 24.35MB
                            Workload MACs : 3262.50MOPS
                          IO Memory Space : 2.25MB
                               Mean Value : 104, 107, 123,
                               Node Count : 55
                              Tensor Count : 56
                     Input Node(s)(H*W*C)
                                 conv1(0) : 224*224*3
                    Output Node(s)(H*W*C)
                               fc1000(0) : 1*1*1000


                             Kernel Name : resnet50_1
--------------------------------------------------------------------------------
                             Kernel Type : CPUKernel
                     Input Node(s)(H*W*C)
                                    prob : 1*1*1000
                    Output Node(s)(H*W*C)
                                    prob : 1*1*1000
```

Figure 29: DNNC Compilation Log for TensorFlow ResNet-50

Programming with DNNDK

To develop deep learning applications on the DPU, three types of work must be done:

- Use DNNDK APIs to manage DPU kernels.
  - DPU kernel creation and destruction.

    - DPU task creation.
    - Managing input and output tensors.
- Implement kernels not supported by the DPU on the CPU.
- Add pre-processing and post-processing routines to read in data or calculate results.

The sample code for managing the DPU kernels and tasks are programmed in the `main()` function.

```
int main(void) {
    /* DPU Kernels/Tasks for running ResNet-50 */
    DPUKernel* kernelConv;
    DPUTask* taskConv;
    /* Attach to DPU driver and prepare for running */
    dpuOpen();
    /* Create DPU Kernels for CONV Nodes in ResNet-50 */
    kernelConv = dpuLoadKernel(KERNEL_CONV);
    /* Create DPU Tasks for CONV Nodes in ResNet-50 */
    taskConv = dpuCreateTask(kernelConv, 0);

    /* Run CONV Kernel for ResNet-50 */
    runResnet50(taskConv);
    /* Destroy DPU Tasks & release resources */
    dpuDestroyTask(taskConv);
    /* Destroy DPU Kernel & release resources */
    dpuDestroyKernel(kernelConv);
    /* Detach DPU driver & release resources */
    dpuClose();
    return 0;

}
```

The main() operations include:

- Call `dpuOpen()` to open the DPU device.
- Call `dpuLoadKernel()` to load the DPU kernel reset50_0.
- Call `dpuCreateTask()` to create task for each DPU kernel.
- Call `dpuDestroyKernel()` and `dpuDestroyTask()` to destroy DPU kernel and task.
- Call `dpuClose()` to close the DPU device.

The main image classification work is done in the function `runResnet50()`, which performs the following operations:

- Fetches an image using the OpenCV function `imread()` and set it as the input to the DPU kernel `resnet50_0` by calling the `dpuSetInputImage2()` API.
- Calls `dpuRunTask()` to run the `taskConv` convolution operation in the ResNet-50 network model.
- Does softmax on the CPU using the output of the fully connected operation as input.
- Outputs the top-5 classification category and the corresponding probability.

```
Mat image = imread(baseImagePath + imageName);
dpuSetInputImage2(taskConv, CONV_INPUT_NODE, image);
```

```
dpuRunTask(taskConv);

/* Get FC result and convert from INT8 to FP32 format */
dpuGetOutputTensorInHWCFP32(taskConv, FC_OUTPUT_NODE,
                                FCResult, channel);
CPUCalcSoftmax(FCResult, channel, softmax);
TopK(softmax, channel, 5, kinds);
```

Compiling the Hybrid Executable

To generate the hybrid executable, change to the `$dnndk_pkg/samples/resnet50` directory, and run `make`. This compiles the application source code to CPU binary code, and then links it against the DPU kernels `dpu_resnet50_0.elf`.

Running the Application

In the `$dnndk_pkg/samples/resnet50` directory, execute `./resnet50` to run this application, and see its output.

DECENT Overview

The process of inference is computation intensive and requires a high memory bandwidth to satisfy the low-latency and high-throughput requirement of edge applications.

DECENT™ (Deep Compression Tool), employs coarse-grained pruning, trained quantization and weight sharing to address these issues while achieving high performance and high energy efficiency with very small accuracy degradation.

DECENT includes two capabilities: Coarse-Grained Pruning and quantization. These reduce the number of required operations and quantize the weights. The whole working flow of DECENT is shown in Chapter 13: Python Programming APIs. In this release, only the quantization tool(DECENT_Q) is included. Contact with DNNDK support team if pruning tool is necessary for your project evaluation.

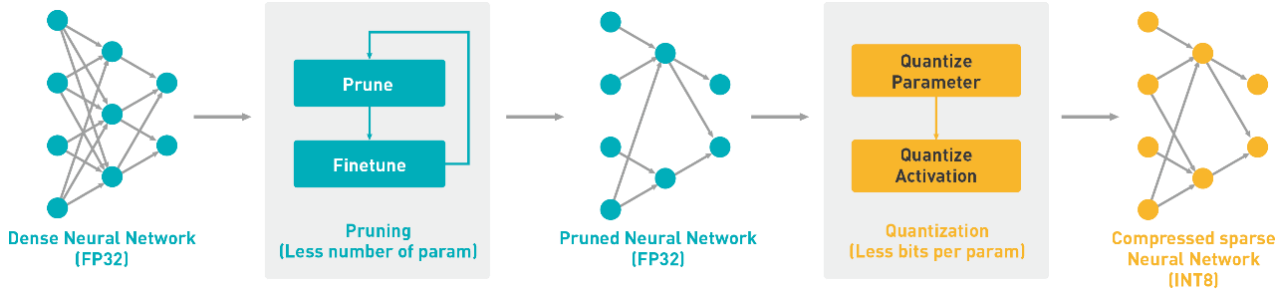


Figure 30: DECENT Pruning and Quantization Flow

Generally, 32-bit floating-point weights and activation values are used when training neural networks. By converting the 32-bit floating-point weights and activations to 8-bit integer (INT8), the DECENT quantize tool can reduce the computing complexity without losing prediction accuracy. The fixed-point network model requires less memory bandwidth, thus providing faster speed and higher power efficiency than the floating-point model. This tool supports common layers in neural networks, such as convolution, activation, pooling, fully connected, and batchnorm.

There is no need to retrain the network after the quantize calibration process, instead only a small set of images is needed to analyze the distribution of activation values for calibration. The quantization time ranges from a few seconds to several minutes, depending on the size of the neural network. The quantize finetuning process are used to further improve the accuracy of quantized models and needs train dataset. Several epochs are needed for quantize finetuning according to our experiments, time ranges from several minutes to hours.

Note: *DECENT_Q supports Caffe and Tensorflow now. DECENT_Q(TF) v0.3.0 is based on Tensorflow 1.12.*

DECENT Working Flow

The overall workflow of model quantization are as follows：

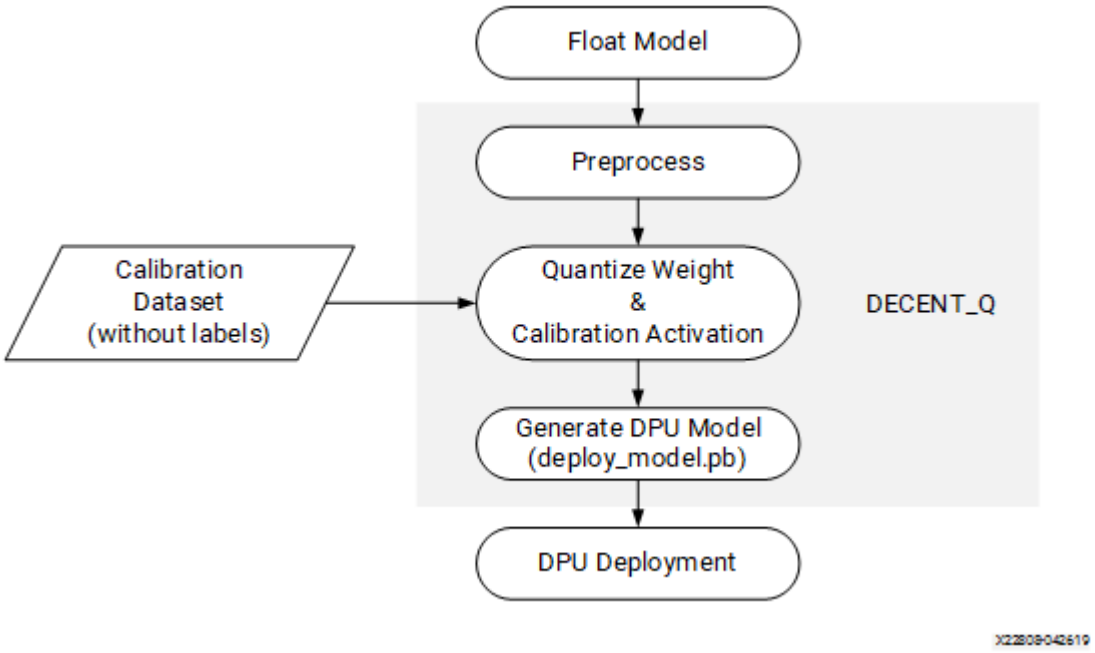


Figure 31: DECENT Workflow

As shown above, the DECENT takes a float model as input (prototxt & caffemodel for Caffe version, frozen GraphDef file for TensorFlow version), does some preprocessing (folds batchnorms and removes useless nodes), and then quantizes the weights/biases and activations to the given bit width.

To improve the precision of the quantized graph, DECENT needs to run some iterations of inference of the model to calibrate the activation; therefore, a calibration dataset input is need. Because there is no need for back propagation, no image labels are needed.

After calibration, the quantized model is transformed to DPU deployable model named `deploy.prototxt/deploy.caffemodel` by Caffe version DECENT or `deploy_model.pb` for TensorFlow version DECENT, which follows the data format of DPU. Then it can be compiled by DNNC compiler and deployed to DPU. Note that the quantized model cannot be taken in by standard vision Caffe or TensorFlow framework.

DECENT (Caffe Version) Usage

The options supported by DECENT are shown below.

Table 7: DECENT Options List

Name	Type	Optional	Default	description
model	String	Required	-	Floating-point prototxt file (e.g. "float.prototxt").
weights	String	Required	-	The pre-trained floating-point weights (e.g." float.caffemodel").
weights_bit	Int32	Optional	8	Bit width for quantized weight and bias.
data_bit	Int32	Optional	8	Bit width for quantized activation.
method	Int32	Optional	0	Quantization methods, including 0 for non-overflow and 1 for min-diffs. Method 0 demands shorter execution time compared with method 1. For non-overflow method, make sure no values are saturated during quantization. The results can be easily affected by outliers. For min-diffs method, it allows saturation for quantization to get lower quantization difference, higher endurance to outliers. It usually ends with narrower ranges than non-overflow method.
calib_iter	Int32	Optional	100	Max iterations for calibration.
auto_test	Bool	Optional	FALSE	Run test after calibration, test dataset required.
test_iter	Int32	Optional	50	Max iterations for testing.
output_dir	String	Optional	quantize_results	Output directory for the fixed-point results.
gpu	String	Optional	0	GPU device id for calibration and test
ignore_layers	String	Optional	none	List of layers to ignore during quantization.
ignore_layers_file	String	Optional	none	Protobuf file which defines the layers to ignore during quantization, starting with 'ignore_layers:'

DECENT (Caffe Version) Working Flow

Prepare the Neural Network Model

Before running DECENT, prepare the Caffe model in floating-point format and calibration data set, including:

- Caffe floating-point network model prototxt file. Set the data layer to be consistent with the path of the calibration dataset.
- Pre-trained Caffe floating-point network model caffemodel file.
- Calibration data set. The calibration set is usually a subset of the training set or actual application images (at least 100 images). If you are using the ImageDataLayer as data layer, please make sure to set the source and root_folder in image_data_param to the actual calibration image list and image folder path, as shown in the following figure.

  Note: DECENT cannot quantize the model correctly without calibration dataset, if only the shape if given in the prototxt, please add a data layer to load calibration dataset.

```
# ResNet-50
name: "ResNet-50"
layer {
  name: "data"
  type: "ImageData"
  top: "data"
  top: "label"
  include {
    phase: TRAIN
  }
  transform_param {
    mirror: false
    mean_value: 104
    mean_value: 107
    mean_value: 123
  }
  image_data_param {
    source: "./data/imagenet_256/calibration.txt"
    root_folder: "./data/imagenet_256/calibration_images/"
    batch_size: 10
    shuffle: false
    new_height: 224
    new_width: 224
  }
}
```

Figure 32: Sample Caffe Layer for Quantization

Note: Only the 3-mean-value format is supported by DECENT. Convert to the 3-mean-value format as required.

Note: A known issue is that the MultiBoxLoss layer in some SSD-like models will cause quantize problem, please remove this layer before quantizing. This will not affect the quantization process because the loss layer has no contribution for inference. This issue will be fixed in the next release.

Run DECENT

Run the following command line to generate a fixed-point model:

```
$decent quantize -model float.prototxt -weights float.caffemodel [options]
```

In the above command line, `[options]` stands for optional parameters. The three commonly used options are shown below:

- **weights_bit**: Bit width for quantized weight and bias (default is 8).
- **data_bit**: Bit width for quantized activation (default is 8).
- **method**: Quantization method.
  "0" indicates non-overflow method, and "1" indicates min-diffs mothed. The default method is 0. Non-overflow method makes sure no values are saturated during quantization. The results can be easily affected by outliers. Min-diffs method allows saturation for quantization to get lower quantization difference, higher endurance to outliers. It usually ends with narrower ranges than non-overflow method.

Output

After successful execution of the above command, two files are generated (under the default directory `./quantize_results/`), which can be used as input files to DNNC:

- fixed-point model network (`deploy.prototxt`)
- fixed-point weights (`deploy.caffemodel`)

DECENT (TensorFlow Version) Usage

The options supported by DECENT_Q are shown in the following table.

Table 8: DECENT Required Options List

Name	Type	Description
Common Configuration		
--input_frozen_graph	String	TensorFlow frozen `GraphDef` file of the floating-point model, used for quantize calibration.
--input_nodes	String	The name list of input nodes of the quantize graph, used together with –output_nodes, comma separated. Input nodes and output_nodes are the start and end points of quantization, the subgraph between them will be quantized if quantizable. Notes: ● It is recommended to set –input_nodes to be the last nodes of the preprocessing part and to set –output_nodes to be the last nodes before the post-processing part, because some operations in the preprocessing

		and post-processing parts are not quantizable and may cause error when compiled by DNNC if you need to deploy the quantized model to DPU. ● The input nodes may not be the same as the placeholder nodes of the graph.
--output_nodes	String	The name list of output nodes of the quantize graph, used together with –input_nodes, comma separated. Input nodes and output_nodes are the start and end points of quantization, the subgraph between them will be quantized if quantizable. Notes: ● It is recommended to set –input_nodes to be the final nodes of the preprocessing part and to set –output_nodes to be the last nodes before the post-processing part, because some operations in the preprocessing and post-processing parts are not quantizable and may cause error when compiled by DNNC if you need to deploy the quantized model to DPU.
--input_shapes	String	The shape list of input_nodes, must be a 4-dimension shape for each node, comma separated, e.g. 1,224,224,3; support unknown size for batch_size, e.g. ?,224,224,3; In case of multiple input_nodes, please assign shape list of each node, separated by `:`. e.g. ?,224,224,3:?,300,300,1.
--input_fn	String	The function that provides input data for the graph, used with calibration dataset. The function format is `module_name.input_fn_name`, e.g. 'my_input_fn.input_fn'. The input_fn should take a `int` object as input which indicating the calibration step and should return a dict`(placeholder_node_name, numpy.Array)` object for each call, which will be fed into the model's placeholder operations. E.g. assign –input_fn to my_input_fn.calib_input, and write calib_input function in my_input_fn.py as: def calib_input_fn: # read image and do some preprocessing return {"placeholder_1": input_1_nparray, "placeholder_2": input_2_nparray} Notes: ● Users do not need to do in-graph preprocessing again in input_fn, as the subgraph before –input_nodes will be remained during quantization. ● Remove pre-defined input_fn(including default and random) as they are not commonly used. Users should handle the preprocessing part which is not in the graph file in the input_fn.
Quantize Configuration		
--weight_bit	Int32	Bit width for quantized weight and bias. Default: 8
--activation_bit	Int32	Bit width for quantized activation.

		Default: 8
--method	Int32	The method for quantization 1) 0: non-overflow method, make sure no values are saturated during quantization, may get worse results in case of outliers. 2) 1: min-diffs method, allow saturation for quantization to get lower quantization difference, higher tolerance to outliers. Usually ends with narrower ranges than non-overflow method. Choices: [0, 1] Default: 1
--calib_iter	Int32	The iterations of calibration, total number of images for calibration = calib_iter * batch_size. Default: 100
--ignore_nodes	String	The name list of nodes to be ignored during quantization. ignored nodes will be left unquantized during quantization.
--skip_check	Int32	If set 1, the check for float model will be skipped, useful when only part of the input model is quantized. Choices: [0, 1] Default: 0
--align_concat	Int32	The strategy for alignment of the input quantize position for concat nodes. Set 0 to align all concat nodes, 1 to align the output concat nodes, 2 to disable alignment. Choices: [0, 1, 2] Default: 0
--output_dir	String	The directory to save the quantization results. Default: "./quantize_results"
Dump Configuration		
--max_dump_batches	Int32	The maximum number of batches for dumping.
--dump_float	Int32	If set 1, the float weights and activations will also be dumped. Choices: [0, 1] Default: 0
Session Configurations		
--gpu	String	The gpu device's id used for quantization, comma separated.
--gpu_memory_fraction	float	The gpu memory fraction used for quantization, between 0-1. Default: 0.5
Others		
--help		Show all available options of DECENT_Q.
--version		Show DECENT_Q version information.

DECENT (TensorFlow Version) Working Flow

Step 1: Prepare float model

Before running DECENT_Q, prepare the Frozen Tensorflow model in floating-point format and calibration set, including:

Table 9: Input Files for DECENT_Q

No.	Name	Description
1	frozen_graph.pb	Floating-point frozen graph
2	calibration dataset	A subset of the training set containing 100 to 1000 images
3	Input_fn	An input function to convert the calibration dataset to the frozen_graph 's input data during quantize calibration. Usually will do some data preprocessing and augmentation

1) How to get the frozen graph

In most situations, training a model with TensorFlow will give you a folder containing a GraphDef file (usually ending with the .pb or .pbtxt extension) and a set of checkpoint files. What you need for mobile or embedded deployment is a single GraphDef file that's been 'frozen', or had its variables converted into inline constants so everything's in one file. To handle the conversion, Tensorflow provided freeze_graph.py, which is automatically installed with DECENT_Q.

An example of command-line usage is:

```
$ freeze_graph \
    --input_graph  /tmp/inception_v1_inf_graph.pb \
    --input_checkpoint  /tmp/checkpoints/model.ckpt-1000 \
    --input_binary  true \
    --output_graph  /tmp/frozen_graph.pb \
    --output_node_names  InceptionV1/Predictions/Reshape_1
```

Note: *As the operations of data preprocessing and loss functions are not needed for inference and deployment, the frozen_graph.pb should only include the main part of the model. In particular, the data preprocessing operations should be taken in the "Input_fn" to generate correct input data for quantize calibration.*

Note: *Type `freeze_graph --help` for more options*

Note: *The input and output nodes names will vary depending on the model, but you can inspect and estimate them with decent_q. An example of command-line usage is:*

```
$ decent_q inspect --input_frozen_graph=/tmp/inception_v1_inf_graph.pb
```

The estimated input and output nodes cannot be used for the quantization part if the graph has in-graph preprocessing and post processing, because some operations in the preprocessing and post-processing parts are not quantizable and may cause error when compiled by DNNC if you need to deploy the quantized model to DPU.

*Another way to get the graph's input and output name is by visualizing the graph, both **tensorboard** and **netron** can do this. An example of using netron is:*

```
$ pip install netron
```

```
$ netron /tmp/inception_v3_inf_graph.pb
```

2) How to get the calibration dataset and input function

The calibration set is usually a subset of the training/validation dataset or actual application images (at least 100 images for performance). The input function is a python importable function to load calibration dataset and perform data preprocessing. DECENT_Q can accept an input_fn to do the preprocessing which is not saved in the graph. If the preprocessing subgraph is saved into the frozen graph then the input_fn only needs to read the images from dataset and return a feed_dict.

Custom input function:

The function input is format is `module_name.input_fn_name`, e.g. 'my_input_fn.calib_input'. The input_fn should take a `int` object as input indicating the calibration step number and should return a dict`(placeholder_name, numpy.Array)` object for each call, which will be fed into the model's placeholder nodes when running inference. The shape of numpy.array should be consistent with the placeholders.

The pseudo code example looks like below:

```
$ "my_input_fn.py"
def calib_input(iter):
"""A function that provides input data for the calibration
Args:
iter: A `int` object, indicating the calibration step number
Returns:
    dict( placeholder_name, numpy.array): a `dict` object, which will be fed
into the model
"""
  image = load_image(iter)
  preprocessed_image = do_preprocess(image)
  return {"placeholder_name": preprocessed_images}
```

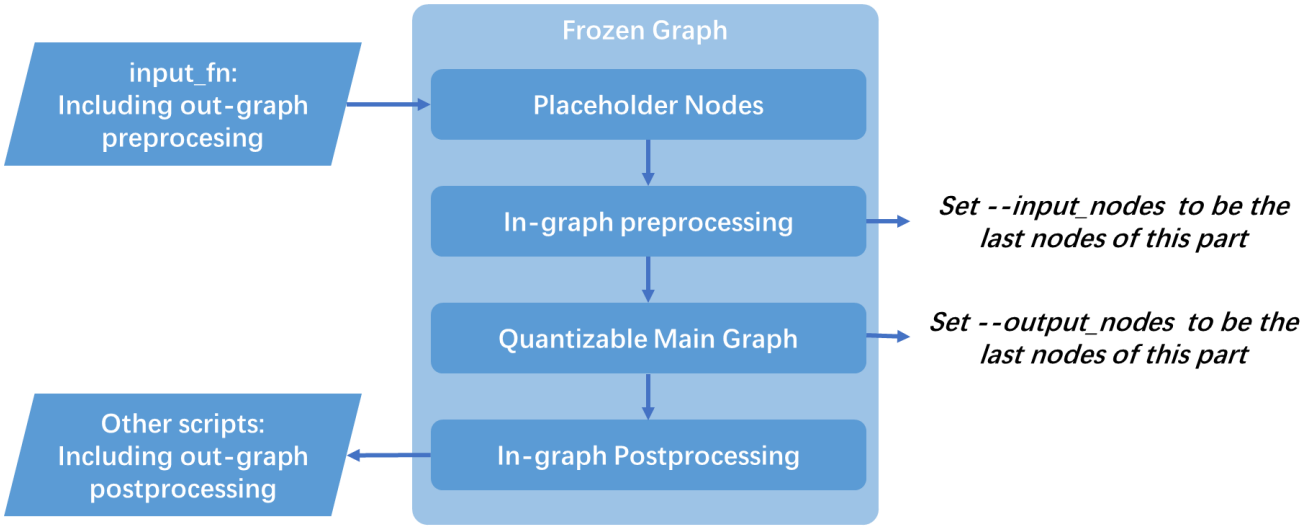
Step 2: Run DECENT_Q

Run the following command line to quantize the model:

```
$decent_q quantize \
   --input_frozen_graph ${frozen_graph_pb_file} \
   --input_nodes  ${input_nodes} \
   --input_shapes  ${input_shapes} \
   --output_nodes   ${output_nodes} \
   --input_fn  ${input_fn} \
   [options]
```

1) How to set the --input_nodes and --output_nodes

The input_nodes and output_nodes arguments are the name list of input nodes of the quantize graph. Input nodes and output_nodes are the start and end points of quantization, the main graph between them will be quantized if quantizable, as shown in the following graph.



Notes:

- It is recommended to set –input_nodes to be the last nodes of the preprocessing part and to set –output_nodes to be the last nodes of the main graph part, because some operations in the preprocessing and post-processing parts are not quantizable and may cause errors when compiled by DNNC if you need to deploy the quantized model to DPU.
- The input nodes may not be the same as the placeholder nodes of the graph, if no in-graph preprocessing part is in the frozen graph, the placeholder nodes should be set to input_nodes.
- The input_fn should be consistent with the placeholder nodes.

2) How to set the options

In the above command line, the [options] stands for optional parameters. The commonly used options are shown below:

- **weight_bit**: bit width for quantized weight and bias (default is 8)
- **activation_bit**: bit width for quantized activation (default is 8)
- **method**: Quantization methods, including 0 for non-overflow and 1 for min-diffs. Method 0 demands shorter execution time compared with method 1. For non-overflow method, make sure no values are saturated during quantization. The results can be easily affected by outliers. For min-diffs method, it allows saturation for quantization to get lower quantization difference, higher tolerance to outliers. It usually ends with narrower ranges than non-overflow method.

Step 3: Output

After successful execution of the above command, two files will be generated in ${output_dir}:

- quantize_eval_model.pb is used to evaluate on CPU/GPU, and can be to simulate the results on hardware.

Note: Users need to 'import tensorflow.contrib.decent_q' explicitly in the evaluation python script to register the custom quantize operation *as tensorflow.contrib is lazy loaded now.*

- deploy_model.pb is used to compile the DPU codes and deploy on it, which can be used as the input files to DPU Compiler(DNNC).

Table 10: DECENT_Q output files

No.	Name	Description
1	deploy_model.pb	Quantized model for DNNC (extended Tensorflow format)
2	quantize_eval_model.pb	Quantized model for evaluation

Step 4: Dump quantize simulation results

After deployment of the quantized model, sometimes we need to compare the simulation results on CPU/GPU and the output values on DPU. DECENT_Q supports dumping the simulation results with the quantize_eval_model.pb generated in step 3.

Run the following command line to dump the quantize simulation results:

```
$decent_q dump \
   --input_frozen_graph  quantize_results/quantize_eval_model.pb \
   --input_fn  dump_input_fn \
   --max_dump_batches 1 \
   --dump_float 0 \
   --output_dir quantize_reuslts \
```

The input_fn for dumping are similar to the input_fn for quantize calibration, but the batch size is often set to 1 to be consistent with the DPU results.

After successful execution of the above command, dump results will be generated in ${output_dir}. There will be folders in ${output_dir}, each folder contains a dump results for a batch of input data. In the folders, results for each node are saved separately. For each quantized node, results will be saved in "*_int8.bin" and "*_int8.txt" format. If dump_float is set to 1, the results for unquantized nodes will alse be dumped. The "/" symbol will be replaced by "_" for simplicity. Examples for dump results are as below:

Batch No.	Quant	Node Name	Saved files
1	Yes	resnet_v1_50/conv1/biases/wquant	{output_dir}/dump_results_1/resnet_v1_50_conv1_biases_wquant_int8.bin {output_dir}/dump_results_1/resnet_v1_50_conv1_biases_wquant_int8.txt
2	No	Resnet_v1_50/conv1/biases	{output_dir}/dump_results_2/resnet_v1_50_conv1_biases.bin {output_dir}/dump_results_2/resnet_v1_50_conv1_biases.txt

DNNC Overview

The architecture of the Deep Neural Network Compiler (DNNC) compiler is shown in the following figure. The front-end parser is responsible for parsing the Caffe/TensorFlow model and generates an intermediate representation (IR) of the input model. The optimizer handles optimizations based on the IR, and the code generator maps the optimized IR to DPU instructions.

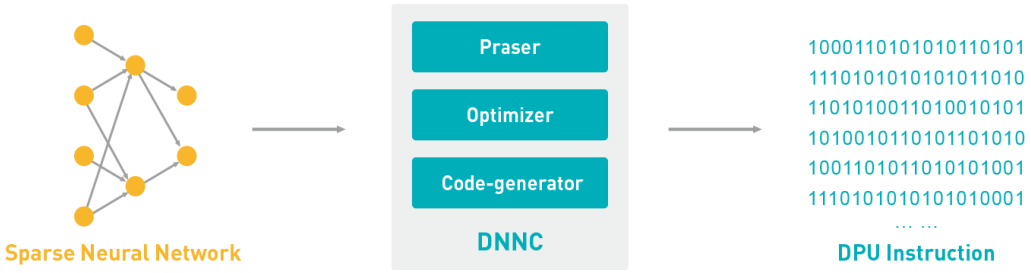


Figure 33: DNNC Components

Using DLet

DLet is DNNDK host tool designed to parse and extract various DPU configuration parameters from DPU Hardware Handoff file `HWH` generated by Vivado. The usage info of DLet is shown below.

```
Usage: dlet <option>
 Options are:
  -v  --version    Display version of DLet
  -f  --file       Specity hardware hand-off(HWH) file
  -h  --help       Display the usage of DLet
```

Figure 34: Dlet Usage Options

For Vivado project, DPU `HWH` is located under the following directory by default. `<prj_name>` is Vivado project name, and `<bd_name>` is Vivado block design name.

```
<prj_name>/<prj_name>.srcs/sources_1/bd/<bd_name>/hw_handoff/<bd_name>.hwh
```

Running command `dlet -f <prj_name>/<prj_name>.srcs/sources_1/bd/<bd_name>/hw_handoff/<bd_name>.hwh`, DLet outputs the DPU Configuration File `DCF` named in the format of `dpu-dd-mm-yyyy-hh-mm.dcf`, and `dd-mm-yyyy-hh-mm` indicates the timestamp when the DPU `HWH` is created. With the specified `DCF` file, DNNC compiler automatically produces DPU code instructions suited for the DPU configuration parameters.

Note: The DPU IP used in Vivado project should come from DPU TRD v3.0 or higher version. Otherwise, DLet may generate parsing errors. User can get the DPU TRD from https://www.xilinx.com/products/design-tools/ai-inference/ai-developer-hub.html#edge.

Using DNNC

DNNC Options

The Deep Neural Network Compiler (DNNC) requires parameters to control the compilation for neural network models. These parameters are divided into two categories. The first group (shown in Table 11), shows the required parameters, and the next group (shown in 12), shows optional parameters.

DNNC Compilation Mode

DNNC supports two different compilation modes for different purposes:

- **Deployment mode:** This mode is primarily used for deployment purpose. DNNC must be provided with both `deploy.prototxt` and `deploy.caffemodel` files using the `--prototxt` and `--caffemodel` options before compiling Caffe models. In this mode, ELF files are generated by DNNC for model deployment.
- **Dummy mode:** This mode is enabled by providing DNNC with only the `deploy.prototxt` file before compiling Caffe models, and should be used for compilation test purposes only. In this mode, DNNC displays some warnings and no ELF files are generated.

Table 12: DNNC Required Option List

Parameters	Description
`--parser`	Select different parser type for DNNC. Currently DNNC supports two different parsers: • **caffe**: Caffe parser that can parse Caffe *. prototxt and *. caffemodel model files. When this parser type is selected, `'--prototxt'` and `'--caffemodel'` options must be provided with parameters; • **tensorflow**: TensorFlow parser that can parse TensorFlow frozen pb model files. When this parser type is selected, `'--frozen_pb'` must be provided with parameters. **Note:** For compiling Caffe models, you can use DNNC's default Caffe parser. There is no need to specify parser type through this option, but when compiling TensorFlow models, you must select TensorFlow parser type using this option, or DNNC will display an error.
`--prototxt`	Path of Caffe prototxt file. **Notes:**

	• This option is only required for Caffe model type parser. See `--parser` option for details. • When the `--caffemodel` option is not provided with a parameter, DNNC compiles the model with dummy mode. See DNNC Compilation Mode for details.
`--caffemodel`	Path of caffemodel file. **Notes:** • This option is only required for Caffe model type parser. See `--parser` option for details. • When this option is not provided with a parameter, DNNC compiles the model with dummy mode. See DNNC Compilation Mode for details.
`--frozen_pb`	Path of TensorFlow frozen pb file. **Notes:** • This option is only required for TensorFlow model type parser. See `--parser` option for details. The `frozen_pb` file provided must come from DECENT's output, or some unexpected errors will occur.
`--output_dir`	Path of output directory
`--net_name`	Name of neural network
`--dpu`	DPU arch type (supported list: 512FA, 800FA, 1024FA, 1152FA, 1600FA, 2304FA, 3136FA, 4096FA). **Notes**: • For configurable DPU, arch type is no longer enough to express all the features of DPU. So `--dpu` option is deprecated since DNNC version 3.0 and replaced by the new option `--dcf` which covers all DPU configuration parameters. If `--dpu` option is specified, DNNC will report error and exit.
`--dcf`	The path of DPU configuration file. This file should be generated by DLet tool and contains DPU configuration parameters.
`--cpu_arch`	CPU target (supported list: arm32, arm64)

Table 13: DNNC Optional Option List

Parameters	Description
--help	Show all available options of DNNC.
--version	Show DNNC version information. The DPU target version supported by DNNC tool is also displayed.

	Note: For each target version DPU, the suited version DNNC should be used. Check if DPU and DNNC are matchable with the help of running command "dexplorer -w" on evaluation board and "dnnc --version" on host machine separately.
--save_kernel	Whether save kernel description in file or not
--abi	Indicate the ABI version for DPU ELF generated by DNNC. 0 for DNNC to produce legacy ABI version DPU ELF. For prior version N2Cube, it only supports the legacy version DPU ELF. With option "--abi=0", newer version DNNC can generate legacy DPU ELF for forward compatibility. 1 for DNNC to produce the latest ABI version DPU ELF. **Note**: this option is available since DNNC v2.03 and is deprecated in v3.0. If ABI version is specified as 0 in this option in DNNDK v3.0, DNNC will discard it, output a warning message, and use ABI version 1 instead.
--mode	Compilation mode of DPU kernel - debug or normal. debug: the layers of the network model run one by one under the scheduling of N2Cube. With the help of DExplorer, the users can perform debugging or performance profiling for each layer of DPU kernel compiled in debug mode. normal: all layers of network model are packaged into one single DPU execution unit, and there isn't any interrupt involved during each execution. Compared with debug mode, Normal mode DPU kernel delivers better performance and should be used during production release phase.
--dump	Dump different type information, use commas as delimiter when multiple types are given: **graph**: original graph and transformed graph in DOT format. The dump files' names are ended with ".gv" suffix. **weights**: weights and bias data for different layers. The dump files' names are ended with ".weights" or ".bias" suffix. **ir**: immediate representation for different layer in DNNC. The dump files' names are ended with ".ir" suffix. **quant_info**: quaternization information for different layers. The dump file's name is "quant.info". **dcf**: DPU configuration parameters specified during DPU IP block design. The dump file's name is "dpu.dcf.dump". **Note**: The dpu.dcf.dump file is just used for dump purpose and should not be fed to DNNC by "--dcf" option for compilation purpose. **log**: other compilation log generated by DNNC. **all**: dump all listed above. **Note**: all the dumped files except for graph type is decrypted by DNNC. In case of network compilation errors, these dump files can be delivered to DNNDK support team for further analysis.

Compiling ResNet50

To illustrate some basic concepts in DNNC, we will use ResNet-50 as compilation example and suppose that both Average-Pooling and SoftMax operator are not supported in the target DPU. When compiling a neural network, the required options should be specified to DNNC compiler. Refer to the script files provided in the DNNDK release package to become familiar with the use of various DNNC options.

Once the compilation is successful, DNNC will generate ELF objects and kernel information for deployment. These files are located under the folder specified by the DNNC option `output_dir`. The following figure shows a screenshot of the DNNC output when compiling the ResNet-50 network.

```
Compiling network: resnet50
[DNNC][Warning] layer [pool5] (type: Pooling) is not supported in DPU, deploy it in CPU instead.
[DNNC][Warning] layer [prob] (type: Softmax) is not supported in DPU, deploy it in CPU instead.

DNNC Kernel topology "resnet50_kernel_graph.jpg" for network "resnet50"
DNNC kernel list info for network "resnet50"
                               Kernel ID : Name
                                       0 : resnet50_0
                                       1 : resnet50_1
                                       2 : resnet50_2
                                       3 : resnet50_3

                           Kernel Name : resnet50_0
--------------------------------------------------------------------------------
                           Kernel Type : DPUKernel
                             Code Size : 1.26MB
                            Param Size : 22.39MB
                         Workload MACs : 3258.59MOPS
                       IO Memory Space : 2.25MB
                            Mean Value : 104, 107, 123,
                            Node Count : 53
                          Tensor Count : 54
                  Input Node(s)(H*W*C)
                           conv1(0) : 224*224*3
                 Output Node(s)(H*W*C)
              res5c_branch2c(0) : 7*7*2048


                           Kernel Name : resnet50_1
--------------------------------------------------------------------------------
                           Kernel Type : CPUKernel
                  Input Node(s)(H*W*C)
                               pool5 : 7*7*2048
                 Output Node(s)(H*W*C)
                               pool5 : 1*1*2048


                           Kernel Name : resnet50_2
--------------------------------------------------------------------------------
                           Kernel Type : DPUKernel
                             Code Size : 0.02MB
                            Param Size : 1.95MB
                         Workload MACs : 3.91MOPS
                       IO Memory Space : 3.10KB
                            Mean Value : 0, 0, 0,
                            Node Count : 1
                          Tensor Count : 2
                  Input Node(s)(H*W*C)
                            fc1000(0) : 1*1*2048
                 Output Node(s)(H*W*C)
                            fc1000(0) : 1*1*1000


                           Kernel Name : resnet50_3
--------------------------------------------------------------------------------
                           Kernel Type : CPUKernel
                  Input Node(s)(H*W*C)
                               prob : 1*1*1000
                 Output Node(s)(H*W*C)
                               prob : 1*1*1000
```

Figure 35: DNNC Output for ResNet-50

Due to the limited number of operations supported by the DPU (see Table 13: Operators Supported by the DPU), DNNC automatically partitions the target neural network into different kernels when there exist operations not supported by DPU. The users are responsible for the data transfer and communication between different kernels, using APIs provided by N^{2}Cube that can be used for retrieving input and output address based on the input and output nodes of the kernel.

The kernel description information generated by DNNC is illustrated as follows.

- **Kernel ID**: The ID of each kernel generated by DNNC after compilation. Every kernel has a unique id assigned by DNNC. Neural network model will be compiled to several kernels depending on operators supported by DPU, and each kernel will be described in detail in the following.
- **Kernel topology**: The kernel topology description file describes the kernels in the kernel graph view when compilation is finished. The `kernel_graph` file is saved in standard JPEG format with file extension `.jpg` in the output directory specified by the DNNC `--output_dir` option. If graphviz is not installed on the host system, DNNC outputs a `DOT` (graph description language) format file with extension `.gv` instead.
  You can convert the `.gv` format file to a JPEG file using the following command:
  ```
  dot -Tjpg -o kernel_graph.jpg kernel_graph.gv
  ```
- **Kernel Name**: The name of the current kernel. For each DPU kernel, DNNC produces one corresponding ELF object file named as `dpu_kernelName.elf`. For example, `dpu_resnet50_0.elf` and `dpu_resnet50_2.elf` are for DPU kernels `resnet50_0` and `resnet50_2` respectively. The kernel name is expected to be used in the DNNDK programming, allowing N^{2}Cube to identify DPU different kernels correctly. As the container for DPU kernel, DPU ELF file encapsulates the DPU instruction codes and parameters for network model. Since DNNDK v3.1, it includes DPU configuration info for each DPU kernel as well.
- **Kernel Type**: The type of kernel. Three types of kernel are supported by DNNC, see Table 14: DNNC Kernel Types for details.
- **Code Size**: DPU instruction code size in the unit of MB or KB or Bytes for the DPU kernel.
- **Param Size**: the size of parameters for this kernel in the unit of MB for the DPU kernel.
- **Workload MACs**: the total computation workload in the unit of MOPS for the DPU kernel.
- **Mean Value**: mean values for the DPU kernel.
- **Node Count**: the number of DPU nodes for the DPU kernel.
- **Tensor Count**: the number of DPU tensors for the DPU kernel.
- **Input nodes**: All input nodes of the current DPU kernel. And the shape info of each node is listed in the format of height*width*channel. For kernels not supported by the DPU, the user must get the output of the preceding kernel through output nodes and feed them into input nodes of the current node using APIs provided by N^{2}Cube.

- **Output nodes**: All output nodes of the current DPU kernel. And the shape info of each node is listed in the format of height*width*channel. The address and size of output nodes can be extracted using APIs provided by N^{2}Cube.

Note: The fields of Code Size, Param Size, Workload MACs, Mean Value, Node Count and Tensor Count from DNNC compilation log are only available for DPU kernel.

For ResNet-50, its kernel graph in JPEG format is shown in the following figure. The kernel graph node describes the kernel id and its type, while the edge shows the relationship between different kernels in two tuples. The first item represents the output tensor from the source kernel, while the second item shows the input tensor to the destination kernel. The tuple contains two parts, the name of input/output node binding to the tensor, and the tensor index of the input/output node. Using the node name and index provided in the tuple, users can use the APIs provided by N^{2}Cube to get the input or output tensor address.

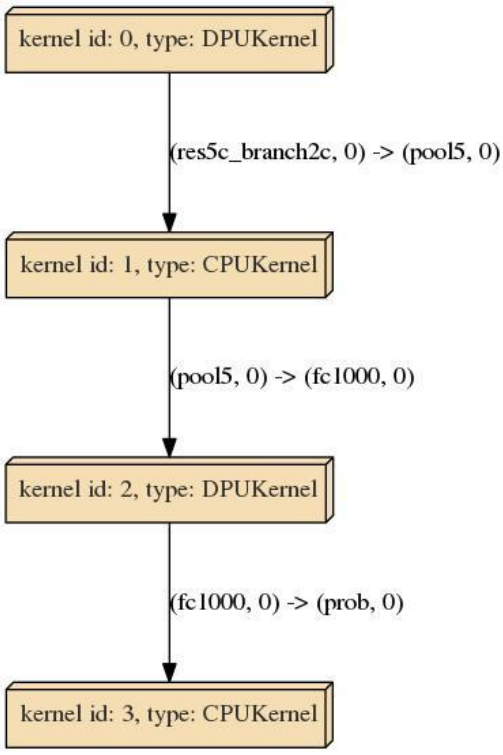


Figure 36: DPU Kernel Graph for ResNet-50

Table 13: Operators Supported by the DPU

Type	Limitations
Convolution	Support kernel-w and kernel-h values ranging from 1 to 8 in any combination.
ReLU	No limitations
Pooling	Max-pooling is supported, and kernel size must be 2x2 or 3x3. Average-pooling is supported by some version DPU IPs. Use "dexplorer -w" to check if it is enabled or not.
Concat	Only concatenation in channel axis is supported.
Element-wise	No limitations
InnerProduct	No limitations

Note: The operators supported by the DPU core might varies according to the DPU configuration parameters. Please refer to DPU IP Product Guide (PG338) for more details.

Table 14: DNNC Kernel Types

Type	Description
DPUKernel	Kernel running on the DPU.
CPUKernel	Kernel running on a CPU; must be implemented by the user.
ParamKernel	Same as CPUKernel; except that DNNC will also generate weights and bias parameters.

Programming Model

Understanding the DPU programming model makes it easier to develop and deploy deep learning applications on the DPU platform. The related concepts include "DPU Kernel", "DPU Task", "DPU Node" and "DPU Tensor". DPU kernel and task are two core concepts for DPU programming.

DPU Kernel

After being compiled by Deep Neural Network Compiler (DNNC) compiler, the neural network model is transformed into an equivalent DPU assembly file, which is then assembled into one ELF object file by Deep Neural Network Assembler (DNNAS). DPU ELF object file is regarded as DPU kernel, which becomes one execution unit from the perspective of runtime N^2Cube after invoking the API `dpuLoadKernel()`. N^2Cube will load DPU kernel, including DPU instructions and network parameters, into the DPU dedicated memory space and allocate hardware resources. After that, each DPU kernel can be instantiated into several DPU tasks by calling `dpuCreateTask()` to enable the multithreaded programming.

DPU Task

Each DPU task is a running entity of a DPU kernel. It has its own private memory space so that multithreaded applications can be used to process several tasks in parallel to improve efficiency and system throughput.

DPU Node

A DPU node is considered a basic element of a network model deployed on the DPU. Each DPU node is associated with input, output and some parameters. Every DPU node has a unique name to allow APIs exported by DNNDK to access its information.

There are three types of nodes: boundary input node, boundary output node, and internal node.

- A **boundary input node** is a node that does not have any precursor in the DPU kernel topology; it is usually the first node in a kernel. Sometimes there might be multiple boundary input nodes in a kernel.
- A **boundary output node** is a node that does not have any successor nodes in the DPU kernel topology.
- All other nodes that are not both boundary input nodes and boundary output nodes are considered as internal nodes.

After compilation, DNNC gives information about the kernel and its boundary input/output nodes. The following figure shows an example after compiling Inception-v1. For DPU kernel 0, `conv1_7x7_s2` is the boundary input node, and `inception_5b_output` is the boundary output node.

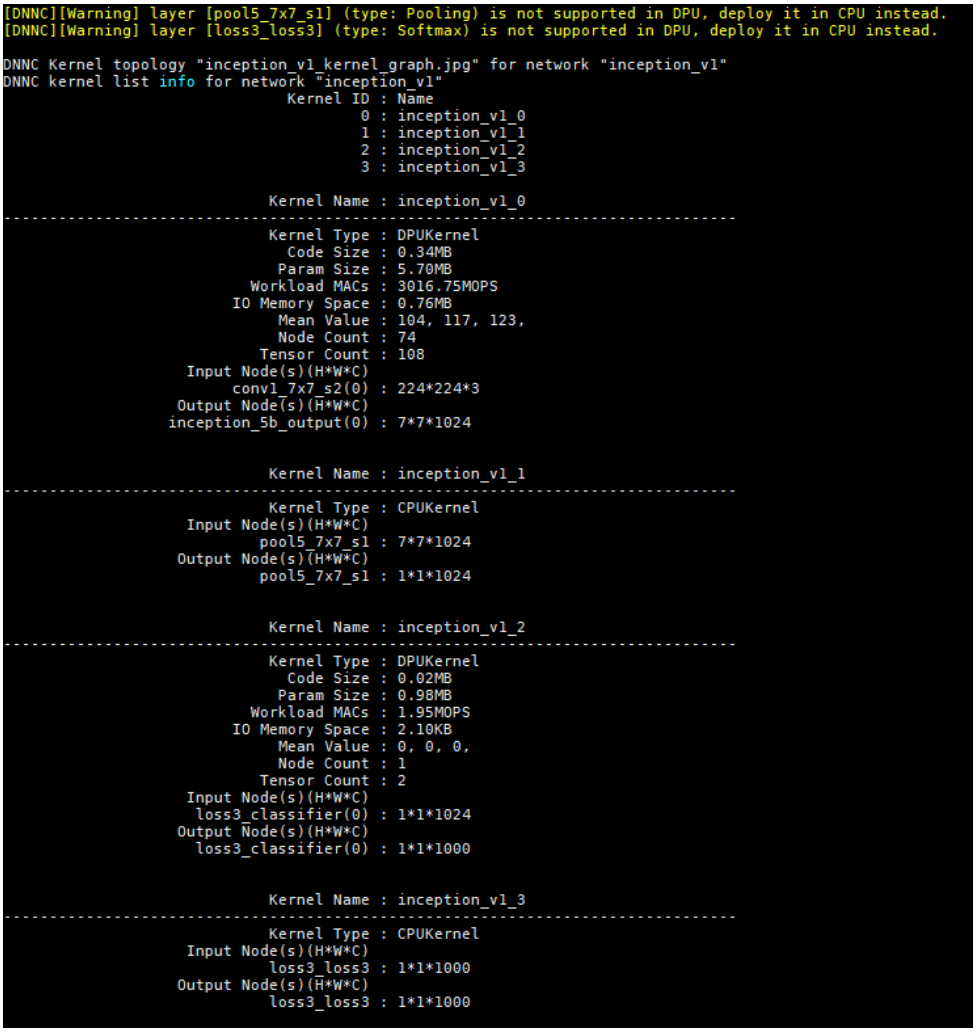


Figure 37: Sample DNNC Compilation Log

When using `dpuGetInputTensor*/dpuSetInputTensor*`, the `nodeName` parameter is required to specify the boundary input node. When a `nodeName` that does not correspond to a valid boundary input node is used, DNNDK gives an error message:

```
[DNNDK] Node "inception_5b_output" is not a Boundary Input Node for Kernel
inception_v1_0.
[DNNDK] Refer to DNNDK user guide for more info about "Boundary Input Node".
```

Similarly, when using `dpuGetOutputTensor*/dpuSetOutputTensor*`, an error is generated when a "`nodeName`" that does not correspond to a valid boundary output node is used:

```
[DNNDK] Node "conv1_7x7_s2" is not a Boundary Output Node for Kernel
inception_v1_0.
[DNNDK] Please refer to DNNDK user guide for more info about "Boundary Output
Node".
```

DPU Tensor

DPU tensor is a collection of multi-dimensional data that is used to store information while running. Tensor properties (such as height, width, channel, and so on) can be obtained using APIs offered by DNNDK.

For the standard image, memory layout for the image volume is normally stored as a contiguous stream of bytes in the format of CHW (Channel*Height*Width). For DPU, memory storage layout for input tensor and output tensor is in the format of HWC (Height*Width*Channel). And the data inside DPU tensor is stored as a contiguous stream of singed 8-bit integer values without padding. Therefore, the users need to pay attention to this layout difference when feeding data into DPU input tensor or retrieving result data from DPU output tensor.Programming Interface

DNNDK offers a set of lightweight C/C++ programming APIs encapsulated in several libraries to smooth the deep learning application development for the DPU. For detailed description of each API, refer to Chapter 12: C++ Programming APIs.

Since DNNDK v3.1, Python programming APIs become available to facilitate the quick network model development through reusing the pre-processing and post-processing Python code developed during the model training phase. Refer to Chapter 13: Python Programming APIs for more information.

It is common to exchange data between CPU and the DPU when programming with DNNDK for DPU. For example, data pre-processed by CPU is fed to DPU for process, and the output produced by DPU might need to be accessed by CPU for further post-processing. To handle this type of operation, DNNDK provides a set of APIs to make it easy for data exchange between CPU and DPU. Some of them are shown below. Their usages are identical to deploy network models for Caffe and TensorFlow.

DNNDK APIs to set input tensor for the computation layer or node:

- `dpuSetInputTensor()`
- `dpuSetInputTensorInCHWInt8()`
- `dpuSetInputTensorInCHWFP32()`
- `dpuSetInputTensorInHWCInt8()`
- `dpuSetInputTensorInHWCFP32()`

DNNDK APIs to get output tensor from the computation layer or node:

- `dpuGetOutputTensor()`
- `dpuGetOutputTensorInCHWInt8()`
- `dpuGetOutputTensorInCHWFP32()`
- `dpuGetOutputTensorInHWCInt8()`
- `dpuGetOutputTensorInHWCFP32()`

DNNDK provides the following APIs to get the start address, size, quantization factor, and shape info for DPU input and output tensor. With such information, the users can freely implement pre-processing source code to feed signed 8-bit integer data into DPU or implement post-processing source code to get DPU result data.

- `dpuGetTensorAddress()`
- `dpuGetTensorSize()`
- `dpuGetTensorScale()`
- `dpuGetTensorHeight()`
- `dpuGetTensorWidth()`
- `dpuGetTensorChannel()`

Caffe Model

For Caffe framework, its pre-processing for model is fixed. DNNDK offers several optimized APIs (like `dpuSetInputImage` and `dpuSetInputImageWithScale`) defined in library libdputils.so to perform image pre-processing on CPU side, such as image scaling, normalization and quantization, and the data is fed into DPU for further processing. Refer to the source code of DNNDK sample ResNet-50 for more details.

TensorFlow Model

TensorFlow framework supports very flexible model pre-processing during model training, such as using BGR or RGB color space for input images. Therefore, DNNDK pre-defined APIs in the library libdputils.so can't be used directly while deploying TensorFlow models. Instead the users need to implement the pre-processing code by themselves.

The following code snippet shows an example to specify image into DPU input tensor for TensorFlow model. Noted that the image color space fed into DPU input Tensor should be the same with the format used during model training. With `data[j*image.rows*3+k*3+2-i]`, the image is fed into DPU in RGB color space. And the process of `image.at<Vec3b>(j,k)[i])/255.0 - 0.5)*2 * scale` is specific to the model being deployed. It should be changed accordingly for the actual model used.

```
void setInputImage(DPUTask *task, const string& inNode, const cv::Mat& image) {
  DPUTensor* in = dpuGetInputTensor(task, inNode);
  float scale = dpuGetTensorScale(in);
  int width = dpuGetTensorWidth(in);
  int height = dpuGetTensorHeight(in);
  int size = dpuGetTensorSize(dpu_in);
  int8_t* data = dpuGetTensorAddress(in);

  for(int i = 0; i < 3; ++i) {
    for(int j = 0; j < image.rows; ++j) {
      for(int k = 0; k < image.cols; ++k) {
          data[j*image.rows*3+k*3+2-i] =
          (float(image.at<Vec3b>(j,k)[i])/255.0 - 0.5)*2 * scale;
      }
     }
   }
}
```

Python is very popularly used for TensorFlow model training. With DNNDK Python APIs, the users can reuse those pre-processing and post-processing Python code during training phase. This can help to speed up the workflow of model deployment on DPU for the quick evaluation purpose. After that it can be transformed into C++ code for better performance to meet the production requirements. The DNNDK sample miniResNet provides a reference to deploy TensorFlow miniResNet model with Python.

Deep learning applications developed for the DPU are heterogeneous programs, which will contain code running on a host CPU (such as x86 or Arm), and code running on the DPU. The compilation process for DPU-accelerated deep learning applications is depicted in the following figure.

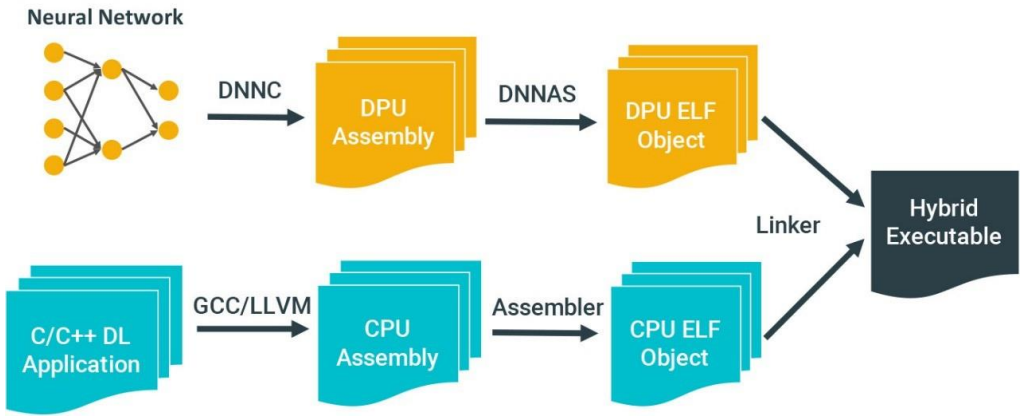


Figure 38: Hybrid Compilation Process

Code that runs on a CPU is programmed in the C/C++ language, which is then processed by a compiler, such as GCC or LLVM. At the same time, computation intensive neural networks are compiled by Deep Neural Network Compiler (DNNC)into DPU binary code for acceleration. In the final stage, CPU and DPU code are linked together by a linker (e.g. GCC) to produce a single hybrid binary executable, which contains all the required information for heterogeneously running on both CPU and DPU.

DPU Shared Library

Under some scenarios, DPU ELF files can't be linked together with DNNDK code into the final hybrid executable, such as DNNDK applications programmed with Python. After Caffe or TensorFlow models are compiled to DPU ELF files, the users can make use of ARM GCC toolchain to transform them into DPU shared libraries so that they stay separately with DNNDK applications and work well as expected.

For x64 host system, ARM cross toolchain like `aarch64-linux-gnu-gcc` for 64-bit ARM or `arm-linux-gnu-gcc` for 32-bit ARM can be used. For DNNDK evaluation boards, `gcc` toolchain can be used. The command samples for ResNet50 look as the followings:

```
aarch64-linux-gnu-gcc -fPIC -shared \
   dpu_resnet50_*.elf -o libdpumodelresnet50.so
```

With `dpu_resnet50_*.elf`, the two DPU ELF files `dpu_resnet50_0.elf` and `dpu_resnet50_2.elf` for ResNet50 model are covered and wrapped into libdpumodelresnet50.so. For each model, all its DPU ELF files should be linked together into one unique DPU shared library in the naming format of `libdpumodelModelName.so`. For ResNet50, `ModelName` should be replaced with `resnet50`. If there are

more than one network models used in a DNNDK application, the users must create one DPU shared library for each of them.

Noted that DPU shared libraries should be placed in the same folder with DNNDK applications, or the folder of `/lib/` or `/usr/lib/` or `/usr/local/lib/`. Otherwise DNNDK API `dpuLoadKernel` will report error.

As described in previous sections, a deep learning application is compiled and linked into a hybrid binary executable. It looks like the same as normal applications. Under the hood, a standard Linux loader and the DPU loader handles how to load and run the hybrid deep learning application. The running model of DPU deep learning applications is shown in the following figure. It is composed of DPU Loader, DPU profiler, DPU runtime library, and DPU driver.

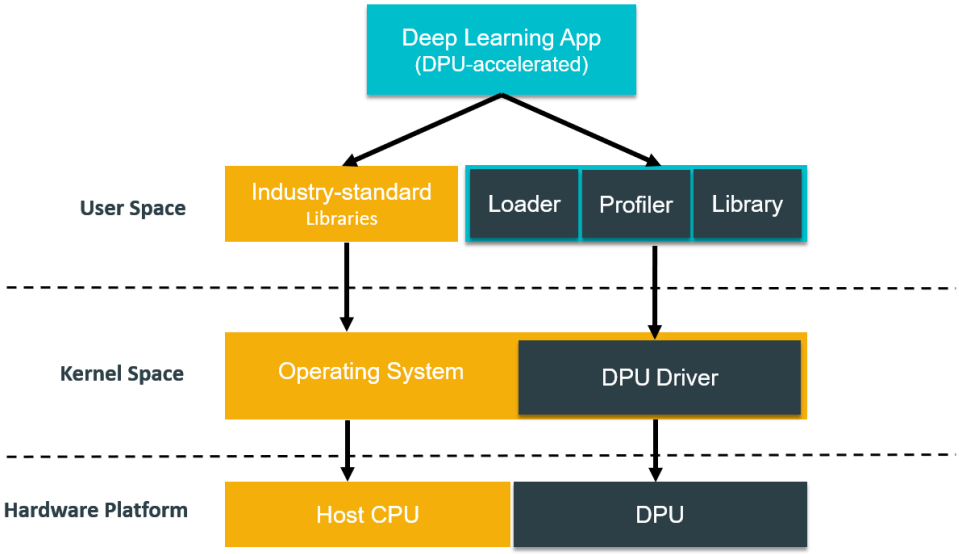


Figure 39: DPU Runtime

The DPU loader handles the transfer of DPU kernels from the hybrid ELF executable into memory and dynamically relocates the memory of DPU code.

This chapter describes the tools included within the DNNDK package, including DPU configuration and checking tool DExplorer, and profiling tool DSight.

DExplorer

DExplorer is a utility running on the target board. It provides DPU running mode configuration, DNNDK version checking, DPU status checking, and DPU core signature checking. The following figure shows the help information about the usage of DExplorer.

```
Usage: dexplorer <option>
 Options are:
  -v  --version    Display version info for each DNNDK component
  -s  --status     Display the status of DPU cores
  -w  --whoami     Display the info of DPU cores
  -m  --mode       Specify DNNDK N2Cube running mode: normal, profile, or debug
  -t  --timeout    Specify DPU timeout limitation in seconds under integer range of [1, 100]
  -h  --help       Display this information
```

Figure 40: DExplorer Usage Options

Check DNNDK version

Running "dexplore -v" will display version information for each component in DNNDK, including N^{2}cube, DPU driver, DExplorer, and DSight.

Check DPU status

DExplorer provides DPU status information, including running mode of N^{2}cube, DPU timeout threshold, DPU debugging level, DPU core status, DPU register information, DPU memory resource and utilization. Figure shows a screenshot of DPU status.

```
root@dp-n1:~# dexplorer -s
[DPU cache]
Enabled

[DPU mode]
normal

[DPU timeout limitation (in seconds)]
5

[DPU Debug Info]
Debug level     : 9
Core 0 schedule : 0
Core 0 interrupt: 0

[DPU Resource]
DPU Core        : 0
State           : Idle
PID             : 0
TaskID          : 0
Start           : 0
End             : 0

[DPU Registers]
VER             : 0x05c1c6bd
RST             : 0x000000ff
ISR             : 0x00000000
IMR             : 0x00000000
IRSR            : 0x00000000
ICR             : 0x00000000

DPU Core        : 0
HP_CTL          : 0x07070f0f
ADDR_IO         : 0x00000000
ADDR_WEIGHT     : 0x00000000
ADDR_CODE       : 0x00000000
ADDR_PROF       : 0x00000000
```

Figure 41: DExplorer Status

Configure DPU Running Mode

DNNDK runtime N^{2}cube supports three kinds of DPU execution modes to help developers to debug and profile DNNDK applications.

Normal Mode

In normal mode, the DPU application can get the best performance without any overhead.

Profile Mode

In this mode, the DPU will turn on the profiling switch. When running deep learning applications in profile mode, N^{2}cube will output to the console the performance data layer by layer while executing the neural network; at the same time, a profile with the name "dpu_trace_[PID].prof" will be produced under the current folder. This file can be used with the DSight tool. The following figure shows a screenshot of this mode.

```
[DNNDK] Performance profile - DPU Kernel "resnet50_0" DPU Task "resnet50_0-5"
================================================================================================
 ID                    NodeName Workload(MOP) Mem(MB) RunTime(ms) Perf(GOPS) Utilization    MB/S
  0                       conv1        236.0     0.4        5.28       44.7       19.4%      67
  1                res2a_branch2a         25.7     0.4        0.23      113.2       49.2%    1719
  2                 res2a_branch1        102.8     1.0        0.95      108.5       47.2%    1044
  3                res2a_branch2b        231.2     0.4        1.34      172.0       74.8%     314
  4                res2a_branch2c        102.8     1.0        1.62       63.3       27.5%     616
  5                res2b_branch2a        102.8     1.0        0.65      159.3       69.3%    1518
  6                res2b_branch2b        231.2     0.4        1.34      172.0       74.8%     314
  7                res2b_branch2c        102.8     1.0        1.62       63.6       27.6%     619
  8                res2c_branch2a        102.8     1.0        0.64      159.8       69.5%    1523
  9                res2c_branch2b        231.2     0.4        1.35      171.9       74.7%     313
 10                res2c_branch2c        102.8     1.0        1.62       63.3       27.5%     616
 11                res3a_branch2a         51.4     0.9        0.41      125.3       54.5%    2197
 12                 res3a_branch1        205.5     1.3        1.49      137.8       59.9%     870
 13                res3a_branch2b        231.2     0.3        1.14      202.6       88.1%     294
 14                res3a_branch2c        102.8     0.6        1.22       84.6       36.8%     466
 15                res3b_branch2a        102.8     0.5        0.58      176.6       76.8%     939
 16                res3b_branch2b        231.2     0.3        1.14      202.6       88.1%     294
 17                res3b_branch2c        102.8     0.6        1.21       84.6       36.8%     466
 18                res3c_branch2a        102.8     0.5        0.58      176.0       76.5%     936
 19                res3c_branch2b        231.2     0.3        1.14      202.6       88.1%     294
 20                res3c_branch2c        102.8     0.6        1.21       84.6       36.8%     466
 21                res3d_branch2a        102.8     0.5        0.58      176.0       76.5%     936
 22                res3d_branch2b        231.2     0.3        1.14      202.5       88.0%     294
 23                res3d_branch2c        102.8     0.6        1.21       84.9       36.9%     468
 24                res4a_branch2a         51.4     0.6        0.49      105.9       46.1%    1164
 25                 res4a_branch1        205.5     1.1        2.01      102.0       44.4%     551
 26                res4a_branch2b        231.2     0.7        1.34      172.9       75.2%     497
 27                res4a_branch2c        102.8     0.5        1.01      101.8       44.3%     508
 28                res4b_branch2a        102.8     0.5        0.71      145.1       63.1%     700
 29                res4b_branch2b        231.2     0.7        1.34      172.9       75.2%     497
 30                res4b_branch2c        102.8     0.5        1.00      102.9       44.7%     513
 31                res4c_branch2a        102.8     0.5        0.71      144.5       62.8%     697
 32                res4c_branch2b        231.2     0.7        1.34      172.7       75.1%     496
 33                res4c_branch2c        102.8     0.5        1.01      101.7       44.2%     508
 34                res4d_branch2a        102.8     0.5        0.71      145.3       63.2%     701
 35                res4d_branch2b        231.2     0.7        1.34      172.3       74.9%     495
 36                res4d_branch2c        102.8     0.5        1.02      100.9       43.9%     504
 37                res4e_branch2a        102.8     0.5        0.71      145.3       63.2%     701
 38                res4e_branch2b        231.2     0.7        1.34      172.8       75.1%     496
 39                res4e_branch2c        102.8     0.5        1.01      101.8       44.3%     508
 40                res4f_branch2a        102.8     0.5        0.70      146.6       63.7%     707
 41                res4f_branch2b        231.2     0.7        1.34      172.8       75.1%     496
 42                res4f_branch2c        102.8     0.5        1.01      101.5       44.1%     507
 43                res5a_branch2a         51.4     0.7        0.70       73.6       32.0%    1044
 44                 res5a_branch1        205.5     2.3        2.81       73.3       31.9%     835
 45                res5a_branch2b        231.2     2.3        1.77      130.6       56.8%    1304
 46                res5a_branch2c        102.8     1.2        1.32       77.8       33.8%     875
 47                res5b_branch2a        102.8     1.1        1.01      101.8       44.3%    1120
 48                res5b_branch2b        231.2     2.3        1.77      130.7       56.8%    1304
 49                res5b_branch2c        102.8     1.2        1.33       77.3       33.6%     869
 50                res5c_branch2a        102.8     1.1        1.01      101.9       44.3%    1121
 51                res5c_branch2b        231.2     2.3        1.78      130.0       56.5%    1298
 52                res5c_branch2c        102.8     1.2        1.28       80.2       34.9%     900

            Total Nodes In Avg:
                           All        7711.9    44.4       64.62      119.3       51.9%     687
================================================================================================
```

Figure 42: N²Cube Profile Mode

Debug Mode

In this mode, the DPU dumps raw data for each DPU computation node during execution, including DPU instruction code in binary format, network parameters, DPU input tensor and output tensor. This makes it easy to debug and locate issues in a DPU application.

Note: Profile mode and debug mode are only available to neural network models compiled into debug mode DPU ELF objects by the Deep Neural Network Compiler (DNNC) compiler.

DPU Signature

New DPU cores have been introduced to meet various deep learning acceleration requirements across different Xilinx® FPGA devices. For example, DPU architectures B1024F, B1152F, B1600F, B2304F, and B4096F are available. Each DPU architecture can implement a different version of the DPU instruction set (which is named as a DPU target version) to support the rapid improvements in deep learning algorithms.

The DPU signature refers to the specification information of a specific DPU architecture version, covering target version, working frequency, DPU core numbers, harden acceleration modules (such as softmax), etc. For configurable DPU since DNNDK v3.1, DPU signature also covers all the DPU configuration parameters.

The `-w` option can be used to check the DPU signature. Figure shows a screenshot of a sample run of `dexplorer -w`.

```
root@zcu102:~# dexplorer -w
[DPU IP Spec]
IP  Timestamp   : 2019-04-16 11:15:00
DPU Core Count  : 3

[DPU Core List]
DPU Core        : #0
DPU Enabled     : Yes
DPU Arch        : B4096F
DPU Target      : v1.4.0
DPU Freqency    : 333 MHz
DPU Features    : Avg-Pooling, LeakyReLU/ReLU6, Depthwise Conv
DPU Core        : #1
DPU Enabled     : Yes
DPU Arch        : B4096F
DPU Target      : v1.4.0
DPU Freqency    : 333 MHz
DPU Features    : Avg-Pooling, LeakyReLU/ReLU6, Depthwise Conv
DPU Core        : #2
DPU Enabled     : Yes
DPU Arch        : B4096F
DPU Target      : v1.4.0
DPU Freqency    : 333 MHz
DPU Features    : Avg-Pooling, LeakyReLU/ReLU6, Depthwise Conv

[DPU Extension List]
Extension Softmax
Enabled         : Yes
```

Figure 43: Sample DPU Signature

For configurable DPU since DNNDK v3.1, dexplorer is enhanced to display all configuration parameters of DPU signature shown as the following figure.

```
root@xilinx-zcu102-2019_1:~$dexplorer -w
[DPU IP Spec]
IP  Timestamp            : 2019-07-24 11:15:00
DPU Core Count           : 3

[DPU Core Configuration List]
DPU Core                 : #0
DPU Enabled              : Yes
DPU Arch                 : B4096
DPU Target Version       : v1.4.0
DPU Freqency             : 325 MHz
Ram Usage                : Low
DepthwiseConv            : Enabled
DepthwiseConv+Relu6      : Enabled
Conv+Leakyrelu           : Enabled
Conv+Relu6               : Enabled
Channel Augmentation     : Enabled
Average Pool             : Enabled

DPU Core                 : #1
```

Figure 44: Sample DPU Signature with Configuration Parameters

DSight

DSight is the DNNDK performance profiling tool. It is a visual performance analysis tool for neural network model profiling. The following figure shows its usage.

```
root@xlnx:~# dsight -h
Usage: dsight <option>
 Options are:
  -p  --profile    Specify DPU trace file for profiling
  -v  --version    Display DSight version info
  -h  --help       Display this information
```

Figure 45: DSight Help Info

By processing the log file produced by the N^{2}cube tracer, DSight can generate an html file, which provides a visual analysis interface for the neural network model. The steps below describe how to use the profiler:

1. Set N^{2}Cube to profile mode using the command `dexplorer -m profile`.
2. Run the deep learning application. When finished, a profile file with the name `dpu_trace_[PID].prof` is generated for further checking and analysis (`PID` is the process ID of the deep learning application).
3. Generate the html file with the DSight tool using the command: `dsight -p dpu_trace_[PID].prof`. An html file with the name `dpu_trace_[PID].html` is generated.
4. Open the generated html file with web browser.

Figure 46: DSight Profiling Charts

DDump

DDump is a utility tool introduced to dump the info encapsulated inside DPU ELF file or hybrid executable or DPU shared library (refer to DPU Shared Library for more details). It can facilitate the users to analyze and debug various issues.

DDump is available for both x86 Linux host and DNNDK evaluation boards. Its usage info is shown in the figure below.

```
DDump - Xilinx DNNDK utility to parse and dump DPU ELF file or
        DPU hybrid executable file
Usage: ddump <option>
 At least one of the following switches must be given:
  -f  --file       Specify DPU hybird executable or DPU ELF object
  -k  --klist      Display each kernel general info from DPU ELF file
                   or DPU hybrid executable file
  -d  --dpu        Display DPU architecture info for each kernel
  -c  --compiler   Display the DNCC compiler version for each kernel
  -a  --all        Display all above info
  -v  --version    Display DDump version info
  -h  --help       Display this help info
```

Figure 47: DDump Usage Options

Check DPU Kernel Info

DDump can dump the following info for each DPU kernel from DPU ELF file or hybrid executable or DPU shared library.

- **Mode**: mode of DPU kernel compiled by DNNC compiler, NORMAL or DEBUG.
- **Code Size:** DPU instruction code size in the unit of MB or KB or Bytes for DPU kernel.
- **Param Size:** parameter size in the unit of MB or KB or Bytes for DPU kernel, including weight and bias.
- **Workload MACs:** the computation workload in the unit of MOPS for DPU kernel.
- **IO Memory Space:** the required DPU memory space in the unit of MB or KB or Bytes for intermediate feature map. For each created DPU task, N^2Cube automatically allocates DPU memory buffer for intermediate feature map.
- **Mean Value:** mean values for DPU kernel.
- **Node Count:** the total number of DPU nodes for DPU kernel.
- **Tensor Count:** the total number of DPU tensors for DPU kernel.
- **Tensor In(H*W*C):** DPU input tensor list and their shape info in the format of height*width*channel.
- **Tensor Out(H*W*C):** DPU output tensor list and their shape info in the format of height*width*channel.

The figure below shows the screenshot of DPU kernel info for ResNet50 DPU ELF file `dpu_resnet50_0.elf` with command `ddump -f dpu_resnet50_0.elf -k`.

```
DPU Kernel List from file dnnc_output/dpu_resnet50_0.elf
                     ID:  Name
                      0:  resnet50_0

DPU Kernel name: resnet50_0
--------------------------------------------------------------
 -> DPU Kernel general info
                   Mode:  NORMAL
              Code Size:  1.28MB
             Param Size:  24.35MB
          Workload MACs:  7358.50MOPS
        IO Memory Space:  2.25MB
             Mean Value:  104, 107, 123
             Node Count:  55
            Tensor Count:  56
         Tensor In(H*W*C)
              Tensor ID-0:  224*224*3
        Tensor Out(H*W*C)
             Tensor ID-55:  1*1*1000
```

Figure 48: DDump DPU Kernel Info for ResNet50

Check DPU Arch Info

For DNNDK v3.1, DPU configuration info from DPU `DCF` is automatically wrapped into DPU ELF file by DNNC compiler for each DPU kernel. Accordingly, DNNC generates the suited DPU instructions according to such DPU configuration parameters. Please refer to DPU IP Product Guide (PG338) for more details about configurable DPU descriptions. DDump can dump out the following DPU architecture info.

- **DPU Target Ver:** the version of DPU instruction set. For DNNDK v3.1 release, it is 1.4.0.
- **DPU Arch Type:** type of DPU architecture, such as B512, B800, B1024, B1152, B1600, B2304, B3136, and B4096.
- **RAM Usage:** low or high RAM usage.
- **DepthwiseConv:** DepthwiseConv engine enabled or not.
- **DepthwiseConv+Relu6:** the operator pattern of DepthwiseConv following by Relu6 enabled or not.
- **Conv+Leakyrelu:** the operator pattern of Conv following by Leakyrelu enabled or not.
- **Conv+Relu6:** the operator pattern of Conv following by Relu6 enabled or not.
- **Channel Augmentation:** an optional feature to improve DPU computation efficiency against channel dimension, especially for those layers whose input channels are much less than DPU channel parallelism.
- **Average Pool:** The Average Pool engine enabled or not.

The above DPU architecture info may vary with the versions of DPU IP. Running command `ddump -f dpu_resnet50_0.elf -d`, one set of DPU architecture info used by DNNC to compile ResNet50 model is shown in the following figure.

```
DPU Kernel List from file dpu_resnet50_0.elf
                     ID:  Name
                      0:  resnet50_0

DPU Kernel name: resnet50_0
------------------------------------------------------------
 -> DPU architecture info
             DPU ABI Ver:  v2.0
DPU Configuration Parameters
          DPU Target Ver:  1.4.0
           DPU Arch Type:  B512
               RAM Usage:  high
           DepthwiseConv:  Enabled
     DepthwiseConv+Relu6:  Enabled
          Conv+Leakyrelu:  Enabled
              Conv+Relu6:  Enabled
    Channel Augmentation:  Enabled
            Average Pool:  Disabled
```

Figure 49: DDump DPU Arch Info for ResNet50

Check DNNC Info

DNNC version info is automatically embedded into DPU ELF file while compiling network model. DDump can help to dump out this DNNC version info, which the users can provide to DNNDK support team for debugging purpose.

Running command `ddump -f dpu_resnet50_0.elf -c` for ResNet50 model, DNNC info is shown in the following figure.

```
DPU Kernel List from file dnnc_output/dpu_resnet50_0.elf
                     ID:  Name
                      0:  resnet50_0

DPU Kernel name: resnet50_0
------------------------------------------------------------
 -> DNNC compiler info
   DNNC Ver: dnnc version v3.00
DPU Target : v1.4.0
Build Label: Jul 22 2019 16:47:08
Copyright @2019 Xilinx Inc. All Rights Reserved.
```

Figure 50: DDump DNNC Info for ResNet50

Legacy Support

DDump also supports to dump the info for legacy DPU ELF file, hybrid executable and DPU shared library generated by prior version DNNDK. One of the main differences is that there is no detailed DPU architecture info.

One example to dump all the info for legacy ResNet50 DPU ELF file with command `ddump -f dpu_resnet50_0.elf -a` is shown in the following figure.

```
DPU Kernel List from file dnnc_output/dpu_resnet50_0.elf
                      ID:  Name
                       0:  resnet50_0

DPU Kernel name: resnet50_0
--------------------------------------------------------------
 -> DPU Kernel general info
                    Mode:  NORMAL
               Code Size:  0.56MB
              Param Size:  24.35MB
           Workload MACs:  7358.50MOPS
         IO Memory Space:  2.25MB
              Mean Value:  104, 107, 123
              Node Count:  55
             Tensor Count:  56
         Tensor In(H*W*C)
              Tensor ID-0:  224*224*3
        Tensor Out(H*W*C)
             Tensor ID-55:  1*1*1000

 -> DPU architecture info
             DPU ABI Ver:  v1.7
          DPU Target Ver:  v1.3.7
            DPU Arch ver:  B4096F

 -> DNNC compiler info
   DNNC Ver: dnnc version v2.03
DPU Target : v1.3.7
Build Label: Jul 22 2019 16:29:39
Copyright @2018 Xilinx Inc. All Rights Reserved.
```

Figure 51: DDump DNNC Info for ResNet50

Chapter 12: C++ Programming APIs

DNNDK provides a lightweight set of C++ programming APIs for deep learning application developers. It consists of two dynamic libraries, DPU runtime N^{2}Cube library `libn2cube` and DPU utility library `libdputils`. The exported APIs for them are individually contained in header file `n2cube.h` and `dputils.h`, which are described in detail in this chapter.

Notes:

- For simplification, you only need to include the header file `dnndk.h` into DNNDK applications. It includes both `n2cube.h` and `dputils.h` by default.
- The subsequent sections give detailed description to each API. Item "**AVAILABILITY**" indicates which DNNDK version the corresponding API became available.

Library libn2cube

Overview

Library libn2cube is the DNNDK core library. It implements the functionality of DPU loader, and encapsulates the system calls to invoke the DPU driver for DPU Task scheduling, monitoring, profiling, and resources management. The exported APIs are briefly summarized in the table below.

NAME	libn2cube.so
DESCRIPTION	DPU runtime library
ROUTINES	dpuOpen() - Open & initialize the usage of DPU device dpuClose() - Close & finalize the usage of DPU device dpuLoadKernel() - Load a DPU Kernel and allocate DPU memory space for its Code/Weight/Bias segments dpuDestroyKernel() - Destroy a DPU Kernel and release its associated resources dpuCreateTask() - Instantiate a DPU Task from one DPU Kernel, allocate its private working memory buffer and prepare for its execution context

	dpuRunTask() - Launch the running of DPU Task **dpuDestroyTask()** - Remove a DPU Task, release its working memory buffer and destroy associated execution context **dpuEnableTaskDump()** - Enable dump facility of DPU Task while running for debugging purpose **dpuEnableTaskProfile()** - Enable profiling facility of DPU Task while running to get its performance metrics **dpuGetTaskProfile()** - Get the execution time of DPU Task **dpuGetNodeProfile()** - Get the execution time of DPU Node **dpuGetInputTensorCnt()** - Get total number of input Tensor of one DPU Task **dpuGetInputTensor()** - Get input Tensor of one DPU Task **dpuGetInputTensorAddress()** - Get the start address of one DPU Task's input Tensor **dpuGetInputTensorSize()** - Get the size (in byte) of one DPU Task's input Tensor **dpuGetInputTensorScale()** - Get the scale value of one DPU Task's input Tensor **dpuGetInputTensorHeight()** - Get the height dimension of one DPU Task's input Tensor **dpuGetInputTensorWidth()** - Get the width dimension of one DPU Task's input Tensor **dpuGetInputTensorChannel()** - Get the channel dimension of one DPU Task's input Tensor **dpuGetOutputTensorCnt()** - Get total number of output Tensor of one DPU Task **dpuGetOutputTensor()** - Get output Tensor of one DPU Task

	dpuGetOutputTensorAddress() - Get the start address of one DPU Task's output Tensor **dpuGetOutputTensorSize()** - Get the size in byte of one DPU Task's output Tensor **dpuGetOutputTensorScale()** - Get the scale value of one DPU Task's output Tensor **dpuGetOutputTensorHeight()** - Get the height dimension of one DPU Task's output Tensor **dpuGetOutputTensorWidth()** - Get the width dimension of one DPU Task's output Tensor **dpuGetOutputTensorChannel()** - Get the channel dimension of one DPU Task's output Tensor **dpuGetTensorSize()** - Get the size of one DPU Tensor **dpuGetTensorAddress()** - Get the start address of one DPU Tensor **dpuGetTensorScale()** - Get the scale value of one DPU Tensor **dpuGetTensorHeight()** - Get the height dimension of one DPU Tensor **dpuGetTensorWidth()** - Get the width dimension of one DPU Tensor **dpuGetTensorChannel()** - Get the channel dimension of one DPU Tensor **dpuSetInputTensorInCHWInt8()** - Set DPU Task's input Tensor with data stored under Caffe order (channel/height/width) in INT8 format **dpuSetInputTensorInCHWFP32()** - Set DPU Task's input Tensor with data stored under Caffe order (channel/height/width) in FP32 format **dpuSetInputTensorInHWCInt8()** - Set DPU Task's input Tensor with data stored under DPU order (height/width/channel) in INT8 format **dpuSetInputTensorInHWCFP32()** - Set DPU Task's input Tensor with data stored under DPU order (channel/height/width) in FP32 format

	dpuGetOutputTensorInCHWInt8() - Get DPU Task's output Tensor and store them under Caffe order (channel/height/width) in INT8 format **dpuGetOutputTensorInCHWFP32()** - Get DPU Task's output Tensor and store them under Caffe order (channel/height/width) in FP32 format **dpuGetOutputTensorInHWCInt8()** - Get DPU Task's output Tensor and store them under DPU order (channel/height/width) in INT8 format **dpuGetOutputTensorInHWCFP32()** - Get DPU Task's output Tensor and store them under DPU order (channel/height/width) in FP32 format **dpuRunSoftmax () -** Perform softmax calculation for the input elements and save the results to output memory buffer. **dpuSetExceptionMode()** - Set the exception handling mode for DNNDK runtime N^{2}Cube. **dpuGetExceptionMode()** - Get the exception handling mode for runtime N^{2}Cube. **dpuGetExceptionMessage()** - Get the error message from error code (always negative value) returned by N^{2}Cube APIs.
INCLUDE FILE	**n2cube.h**

APIs

The prototype and parameter for each API of library libn2cube are shown in detail in the following sections.

dpuOpen()

NAME	dpuOpen()
SYNOPSIS	int dpuOpen()
ARGUMENTS	None

DESCRIPTION	Attach and open DPU device file "/dev/dpu" before the utilization of DPU resources.
RETURNS	0 on success, or negative value in case of failure. Error message "Fail to open DPU device" is reported if any error takes place.
SEE ALSO	dpuClose()
INCLUDE FILE	n2cube.h
AVAILABILITY	v1.07

dpuClose()

NAME	dpuClose()
SYNOPSIS	int dpuClose()
ARGUMENTS	None
DESCRIPTION	Detach and close DPU device file "/dev/dpu" after utilization of DPU resources.
RETURNS	0 on success, or negative error ID in case of failure. Error message "Fail to close DPU device" is reported if any error takes place.
SEE ALSO	dpuOpen()
INCLUDE FILE	n2cube.h
AVAILABILITY	v1.07

dpuLoadKernel()

NAME	dpuLoadKernel()	
SYNOPSIS	DPUKernel *dpuLoadKernel (const char *netName)	
ARGUMENTS	netName	The pointer to neural network name. Use the names produced by Deep Neural Network Compiler (DNNC) after the compilation of neural network. For each DL application, perhaps there are many DPU Kernels existing in its hybrid CPU+DPU binary executable. For each DPU Kernel, it has one unique name for differentiation purpose.
DESCRIPTION	Load a DPU Kernel for the specified neural network from hybrid CPU+DPU binary executable into DPU memory space, including Kernel's DPU instructions, weight and bias.	
RETURNS	The pointer to the loaded DPU Kernel on success, or report error in case of any failure.	
SEE ALSO	dpuDestroyKernel()	
INCLUDE FILE	n2cube.h	
AVAILABILITY	v1.07	

dpuDestroyKernel()

NAME	dpuDestroyKernel()	
SYNOPSIS	int dpuDestroyKernel (DPUKernel *kernel)	
ARGUMENTS	kernel	The pointer to DPU kernel to be destroyed.
DESCRIPTION	Destroy a DPU kernel and release its related resources.	
RETURNS	0 on success, or report error in case of any failure.	
SEE ALSO	dpuLoadKernel()	
INCLUDE FILE	n2cube.h	
AVAILABILITY	v1.07	

dpuCreateTask()

NAME	dpuCreateTask()
SYNOPSIS	int dpuCreateTask (DPUKernel *kernel, Int mode);

ARGUMENTS	kernel	The pointer to DPU Kernel.
	mode	The running mode of DPU Task. There are 3 available modes: T_MODE_NORMAL: default mode identical to the mode value "0". T_MODE_PROF: output profiling information layer by layer while running of DPU Task, which is useful for performance analysis. T_MODE_DUMP: dump the raw data for DPU Task's CODE/BIAS/WEIGHT/INPUT/OUTPUT layer by layer. The file names are in the following format ("netName" refers to the name of neural network; "layerName" refers to the index ID of layer (or Node)): For CODE: netName_layerName_code.txt For WEIGHT: netName_layerName_w.txt For BIAS: netName_layerName_b.txt For INPUT: netName_layerName_i.txt For OUTPUT: netName_layerName_o.txt NOTE: profiling and dump functionality is available only for DPU Kernel generated by DNNC in debug mode.
DESCRIPTION	Instantiate a DPU Task from DPU Kernel and allocate corresponding DPU memory buffer.	
RETURNS	0 on success, or report error in case of any failure.	
SEE ALSO		
INCLUDE FILE	n2cube.h	

AVAILABILITY	v1.07

dpuDestroyTask()

NAME	dpuDestroyTask()	
SYNOPSIS	int dpuDestroyTask (DPUTask *task)	
ARGUMENTS	task	The pointer to DPU Task to be destroyed.
DESCRIPTION	Destroy a DPU Task and release its related resources.	
RETURNS	0 on success, or negative value in case of any failure.	
SEE ALSO	dpuCreateTask()	
INCLUDE FILE	n2cube.h	
AVAILABILITY	v1.07	

dpuRunTask()

NAME	dpuRunTask ()	
SYNOPSIS	int dpuRunTask (DPUTask *task);	
ARGUMENTS	task	The pointer to DPU Task.

DESCRIPTION	Launch the running of DPU Task.
RETURNS	0 on success, or negative value in case of any failure.
SEE ALSO	
INCLUDE FILE	n2cube.h
AVAILABILITY	v1.07

dpuEnableTaskProfile()

NAME	dpuEnableTaskProfile()	
SYNOPSIS	int dpuEnableTaskProfile (DPUTask *task);	
ARGUMENTS	task	The pointer to DPU Task.
DESCRIPTION	Set DPU Task in profiling mode. Note that profiling functionality is available only for DPU Kernel generated by DNNC in debug mode.	
RETURNS	0 on success, or report error in case of any failure.	
SEE ALSO	dpuCreateTask() dpuEnableTaskDump()	
INCLUDE FILE	n2cube.h	
AVAILABILITY	v1.07	

dpuEnableTaskDump()

NAME	dpuEnableTaskDump()	
SYNOPSIS	int dpuEnableTaskDump (DPUTask *task);	
ARGUMENTS	task	The pointer to DPU Task.
DESCRIPTION	Set DPU Task in dump mode. Note that dump functionality is available only for DPU Kernel generated by DNNC in debug mode.	
RETURNS	0 on success, or report error in case of any failure.	
SEE ALSO	dpuCreateTask() dpuEnableTaskProfile()	
INCLUDE FILE	n2cube.h	
AVAILABILITY	v1.07	

dpuGetTaskProfile()

NAME	dpuGetTaskProfile()	
SYNOPSIS	int dpuGetTaskProfile (DPUTask *task);	
ARGUMENTS	task	The pointer to DPU Task.

DESCRIPTION	Get DPU Task's execution time (us) after its running.
RETURNS	The DPU Task's execution time (us) after its running.
SEE ALSO	dpuGetNodeProfile()
INCLUDE FILE	n2cube.h
AVAILABILITY	v1.07

dpuGetNodeProfile()

NAME	dpuGetNodeProfile()	
SYNOPSIS	int dpuGetNodeProfile (DPUTask *task, const char*nodeName);	
ARGUMENTS	task	The pointer to DPU Task.
	nodeName	The pointer to DPU Node's name
DESCRIPTION	Get DPU Node's execution time (us) after DPU Task completes its running.	
RETURNS	The DPU Node's execution time(us) after DPU Task completes its running. Note that this functionality is available only for DPU Kernel generated by DNNC in debug mode.	
SEE ALSO	dpuGetTaskProfile()	
INCLUDE FILE	n2cube.h	
AVAILABILITY	v1.07	

dpuGetInputTensorCnt()

NAME	dpuGetInputTensorCnt()	
SYNOPSIS	Int dpuGetInputTensorCnt (DPUTask *task, const char*nodeName);	
ARGUMENTS	task	The pointer to DPU Task.
	nodeName	The pointer to DPU Node's name. Note that the available names of one DPU Kernel's or Task's input Node are listed out after a neural network is compiled by DNNC. If invalid Node name specified, failure message is reported.
DESCRIPTION	Get total number of input Tensor of one DPU Task's	
RETURNS	The total number of input tensor for specified Node.	
SEE ALSO	dpuGetOutputTensorCnt()	
INCLUDE FILE	n2cube.h	
AVAILABILITY	V2.06	

dpuGetInputTensor()

NAME	dpuGetInputTensor()	
SYNOPSIS	DPUTensor*dpuGetInputTensor (DPUTask *task, const char*nodeName, int idx = 0);	
ARGUMENTS	task	The pointer to DPU Task.
	nodeName	The pointer to DPU Node's name. Note that the available names of one DPU Kernel's or Task's input Node are listed out after a neural network is compiled by DNNC. If invalid Node name specified, failure message is reported.
	idx	The index of a single input tensor for the Node, with default value as 0.
DESCRIPTION	Get DPU Task's input Tensor.	
RETURNS	The pointer to Task's input Tensor on success, or report error in case of any failure.	
SEE ALSO	dpuGetOutputTensor()	
INCLUDE FILE	n2cube.h	
AVAILABILITY	v2.06	

NAME	dpuGetInputTensor()

SYNOPSIS	DPUTensor*dpuGetInputTensor (DPUTask *task, const char*nodeName);	
ARGUMENTS	task	The pointer to DPU Task.
	nodeName	The pointer to DPU Node's name. Note that the available names of one DPU Kernel's or Task's input Node are listed out after a neural network is compiled by DNNC. If invalid Node name specified, failure message is reported.
DESCRIPTION	Get DPU Task's input Tensor.	
RETURNS	The pointer to Task's input Tensor on success, or report error in case of any failure.	
SEE ALSO	dpuGetOutputTensor()	
INCLUDE FILE	n2cube.h	
AVAILABILITY	v1.07	

dpuGetInputTensorAddress()

NAME	dpuGetInputTensorAddress()	
SYNOPSIS	int8_t* dpuGetInputTensorAddress (DPUTask *task, const char*nodeName, int idx = 0);	
ARGUMENTS	task	The pointer to DPU Task.
	nodeName	The pointer to DPU Node's name. Note that the available names of one DPU Kernel's or Task's input Node are listed out after a neural network is compiled by DNNC. If invalid Node name specified, failure message is reported.
	idx	The index of a single input tensor for the Node, with default value as 0.
DESCRIPTION	Get the start address of DPU Task's input Tensor.	
RETURNS	The start addresses to Task's input Tensor on success, or report error in case of any failure.	
SEE ALSO	dpuGetOutputTensorAddress()	
INCLUDE FILE	n2cube.h	
AVAILABILITY	v2.06	

NAME	dpuGetInputTensorAddress()	
SYNOPSIS	int8_t* dpuGetInputTensorAddress (DPUTask *task, const char*nodeName);	
ARGUMENTS	task	The pointer to DPU Task.
	nodeName	The pointer to DPU Node's name. Note that the available names of one DPU Kernel's or Task's input Node are listed out after a neural network is compiled by DNNC. If invalid Node name specified, failure message is reported.
DESCRIPTION	Get the start address of DPU Task's input Tensor.	
RETURNS	The start addresses to Task's input Tensor on success, or report error in case of any failure.	
SEE ALSO	dpuGetOutputTensorAddress()	
INCLUDE FILE	n2cube.h	
AVAILABILITY	v1.07	

dpuGetInputTensorSize()

NAME	dpuGetInputTensorSize()	
SYNOPSIS	int dpuGetInputTensorSize (DPUTask *task, const char*nodeName, int idx = 0);	
ARGUMENTS	task	The pointer to DPU Task.
	nodeName	The pointer to DPU Node's name. Note that the available names of one DPU Kernel's or Task's input Node are listed out after a neural network is compiled by DNNC. If invalid Node name specified, failure message is reported.
	idx	The index of a single input tensor for the Node, with default value as 0.
DESCRIPTION	Get the size (in Byte) of DPU Task's input Tensor.	
RETURNS	The size of Task's input Tensor on success, or report error in case of any failure.	
SEE ALSO	dpuGetOutputTensorSize()	
INCLUDE FILE	n2cube.h	
AVAILABILITY	v2.06	

NAME	dpuGetInputTensorSize()	
SYNOPSIS	int dpuGetInputTensorSize (DPUTask *task, const char*nodeName);	
ARGUMENTS	task	The pointer to DPU Task.
	nodeName	The pointer to DPU Node's name. Note that the available names of one DPU Kernel's or Task's input Node are listed out after a neural network is compiled by DNNC. If invalid Node name specified, failure message is reported.
DESCRIPTION	Get the size (in Byte) of DPU Task's input Tensor.	
RETURNS	The size of Task's input Tensor on success, or report error in case of any failure.	
SEE ALSO	dpuGetOutputTensorSize()	
INCLUDE FILE	n2cube.h	
AVAILABILITY	v1.07	

dpuGetInputTensorScale()

NAME	dpuGetInputTensorScale()	
SYNOPSIS	float dpuGetInputTensorScale (DPUTask *task, const char*nodeName, int idx = 0);	
ARGUMENTS	task	The pointer to DPU Task.
	nodeName	The pointer to DPU Node's name. Note that the available names of one DPU Kernel's or Task's input Node are listed out after a neural network is compiled by DNNC. If invalid Node name specified, failure message is reported.
	idx	The index of a single input tensor for the Node, with default value as 0.
DESCRIPTION	Get the scale value of DPU Task's input Tensor. For each DPU input Tensor, it has one unified scale value indicating its quantization information for reformatting between data types of INT8 and FP32.	
RETURNS	The scale value of Task's input Tensor on success, or report error in case of any failure.	
SEE ALSO	dpuGetOutputTensorScale()	
INCLUDE FILE	n2cube.h	
AVAILABILITY	v2.06	

NAME	dpuGetInputTensorScale()	
SYNOPSIS	float dpuGetInputTensorScale (DPUTask *task, const char*nodeName);	
ARGUMENTS	task	The pointer to DPU Task.
	nodeName	The pointer to DPU Node's name. Note that the available names of one DPU Kernel's or Task's input Node are listed out after a neural network is compiled by DNNC. If invalid Node name specified, failure message is reported.
DESCRIPTION	Get the scale value of DPU Task's input Tensor. For each DPU input Tensor, it has one unified scale value indicating its quantization information for reformatting between data types of INT8 and FP32.	
RETURNS	The scale value of Task's input Tensor on success, or report error in case of any failure.	
SEE ALSO	dpuGetOutputTensorScale()	
INCLUDE FILE	n2cube.h	
AVAILABILITY	v1.07	

dpuGetInputTensorHeight()

NAME	dpuGetInputTensorHeight()	
SYNOPSIS	int dpuGetInputTensorHeight (DPUTask *task, const char*nodeName, int idx = 0);	
ARGUMENTS	task	The pointer to DPU Task.
	nodeName	The pointer to DPU Node's name. Note that the available names of one DPU Kernel's or Task's input Node are listed out after a neural network is compiled by DNNC. If invalid Node name specified, failure message is reported.
	idx	The index of a single input tensor for the Node, with default value as 0.
DESCRIPTION	Get the height dimension of DPU Task's input Tensor.	
RETURNS	The height dimension of Task's input Tensor on success, or report error in case of any failure.	
SEE ALSO	dpuGetInputTensorWidth() dpuGetInputTensorChannel() dpuGetOutputTensorHeight() dpuGetOutputTensorWidth() dpuGetOutputTensorChannel()	
INCLUDE FILE	n2cube.h	
AVAILABILITY	v2.06	

NAME	dpuGetInputTensorHeight()	
SYNOPSIS	int dpuGetInputTensorHeight (DPUTask *task, const char*nodeName);	
ARGUMENTS	task	The pointer to DPU Task.
	nodeName	The pointer to DPU Node's name. Note that the available names of one DPU Kernel's or Task's input Node are listed out after a neural network is compiled by DNNC. If invalid Node name specified, failure message is reported.
DESCRIPTION	Get the height dimension of DPU Task's input Tensor.	
RETURNS	The height dimension of Task's input Tensor on success, or report error in case of any failure.	
SEE ALSO	dpuGetInputTensorWidth() dpuGetInputTensorChannel() dpuGetOutputTensorHeight() dpuGetOutputTensorWidth() dpuGetOutputTensorChannel()	
INCLUDE FILE	n2cube.h	
AVAILABILITY	v1.07	

dpuGetInputTensorWidth()

NAME	dpuGetInputTensorWidth()	
SYNOPSIS	int dpuGetInputTensorWidth (DPUTask *task, const char*nodeName, int idx = 0);	
ARGUMENTS	task	The pointer to DPU Task.
	nodeName	The pointer to DPU Node's name. Note that the available names of one DPU Kernel's or Task's input Node are listed out after a neural network is compiled by DNNC. If invalid Node name specified, failure message is reported.
	idx	The index of a single input tensor for the Node, with default value as 0.
DESCRIPTION	Get the width dimension of DPU Task's input Tensor.	
RETURNS	The width dimension of Task's input Tensor on success, or report error in case of any failure.	

SEE ALSO	dpuGetInputTensorHeight() dpuGetInputTensorChannel() dpuGetOutputTensorHeight() dpuGetOutputTensorWidth() dpuGetOutputTensorChannel()
INCLUDE FILE	n2cube.h
AVAILABILITY	v2.06

NAME	dpuGetInputTensorWidth()	
SYNOPSIS	int dpuGetInputTensorWidth (DPUTask *task, const char*nodeName);	
ARGUMENTS	task	The pointer to DPU Task.
	nodeName	The pointer to DPU Node's name. Note that the available names of one DPU Kernel's or Task's input Node are listed out after a neural network is compiled by DNNC. If invalid Node name specified, failure message is reported.
DESCRIPTION	Get the width dimension of DPU Task's input Tensor.	
RETURNS	The width dimension of Task's input Tensor on success, or report error in case of any failure.	

SEE ALSO	dpuGetInputTensorHeight() dpuGetInputTensorChannel() dpuGetOutputTensorHeight() dpuGetOutputTensorWidth() dpuGetOutputTensorChannel()
INCLUDE FILE	n2cube.h
AVAILABILITY	v1.07

dpuGetInputTensorChannel()

NAME	dpuGetInputTensorChannel()	
SYNOPSIS	int dpuGetInputTensorChannel (DPUTask *task, const char*nodeName, int idx = 0);	
ARGUMENTS	task	The pointer to DPU Task.
	nodeName	The pointer to DPU Node's name. Note that the available names of one DPU Kernel's or Task's input Node are listed out after a neural network is compiled by DNNC. If invalid Node name specified, failure message is reported.
	idx	The index of a single input tensor for the Node, with default value as 0.
DESCRIPTION	Get the channel dimension of DPU Task's input Tensor.	

RETURNS	The channel dimension of Task's input Tensor on success, or report error in case of any failure.
SEE ALSO	dpuGetInputTensorHeight() dpuGetInputTensorWidth() dpuGetOutputTensorHeight() dpuGetOutputTensorWidth() dpuGetOutputTensorChannel()
INCLUDE FILE	n2cube.h
AVAILABILITY	v2.06

NAME	dpuGetInputTensorChannel()	
SYNOPSIS	int dpuGetInputTensorChannel (DPUTask *task, const char*nodeName);	
ARGUMENTS	task	The pointer to DPU Task.
	nodeName	The pointer to DPU Node's name. Note that the available names of one DPU Kernel's or Task's input Node are listed out after a neural network is compiled by DNNC. If invalid Node name specified, failure message is reported.
DESCRIPTION	Get the channel dimension of DPU Task's input Tensor.	

RETURNS	The channel dimension of Task's input Tensor on success, or report error in case of any failure.
SEE ALSO	dpuGetInputTensorHeight() dpuGetInputTensorWidth() dpuGetOutputTensorHeight() dpuGetOutputTensorWidth() dpuGetOutputTensorChannel()
INCLUDE FILE	n2cube.h
AVAILABILITY	v1.07

dpuGetOutputTensorCnt()

NAME	dpuGetOutputTensorCnt()	
SYNOPSIS	Int dpuGetOutputTensorCnt (DPUTask *task, const char*nodeName);	
ARGUMENTS	task	The pointer to DPU Task.
	nodeName	The pointer to DPU Node's name. Note that the available names of one DPU Kernel's or Task's output Node are listed out after a neural network is compiled by DNNC. If invalid Node name specified, failure message is reported.
DESCRIPTION	Get total number of output Tensor for the DPU Task.	

RETURNS	The total number of output tensor for the DPU Task.
SEE ALSO	dpuGetInputTensorCnt()
INCLUDE FILE	n2cube.h
AVAILABILITY	V2.06

dpuGetOutputTensor()

NAME	dpuGetOutputTensor()	
SYNOPSIS	DPUTensor*dpuGetOutputTensor (DPUTask *task, const char*nodeName, int idx = 0);	
ARGUMENTS	task	The pointer to DPU Task.
	nodeName	The pointer to DPU Node's name. Note that the available names of one DPU Kernel's or Task's output Node are listed out after a neural network is compiled by DNNC. If invalid Node name specified, failure message is reported.
	idx	The index of a single output tensor for the Node, with default value as 0.
DESCRIPTION	Get DPU Task's output Tensor.	
RETURNS	The pointer to Task's output Tensor on success, or report error in case of any failure.	

SEE ALSO	dpuGetInputTensor()
INCLUDE FILE	n2cube.h
AVAILABILITY	v2.06

NAME	dpuGetOutputTensor()	
SYNOPSIS	DPUTensor*dpuGetOutputTensor (DPUTask *task, const char*nodeName);	
ARGUMENTS	task	The pointer to DPU Task.
	nodeName	The pointer to DPU Node's name. Note that the available names of one DPU Kernel's or Task's output Node are listed out after a neural network is compiled by DNNC. If invalid Node name specified, failure message is reported.
DESCRIPTION	Get DPU Task's output Tensor.	
RETURNS	The pointer to Task's output Tensor on success, or report error in case of any failure.	
SEE ALSO	dpuGetInputTensor()	
INCLUDE FILE	n2cube.h	
AVAILABILITY	v1.07	

dpuGetOutputTensorAddress()

NAME	dpuGetOutputTensorAddress()	
SYNOPSIS	int8_t* dpuGetOutputTensorAddress (DPUTask *task, const char*nodeName, int idx = 0);	
ARGUMENTS	task	The pointer to DPU Task.
	nodeName	The pointer to DPU Node's name. Note that the available names of one DPU Kernel's or Task's output Node are listed out after a neural network is compiled by DNNC. If invalid Node name specified, failure message is reported.
	idx	The index of a single output tensor for the Node, with default value as 0.
DESCRIPTION	Get the start address of DPU Task's output Tensor.	
RETURNS	The start addresses to Task's output Tensor on success, or report error in case of any failure.	
SEE ALSO	dpuGetInputTensorAddress()	
INCLUDE FILE	n2cube.h	
AVAILABILITY	v2.06	

NAME	dpuGetOutputTensorAddress()	
SYNOPSIS	int8_t* dpuGetOutputTensorAddress (DPUTask *task, const char*nodeName);	
ARGUMENTS	task	The pointer to DPU Task.
	nodeName	The pointer to DPU Node's name. Note that the available names of one DPU Kernel's or Task's output Node are listed out after a neural network is compiled by DNNC. If invalid Node name specified, failure message is reported.
DESCRIPTION	Get the start address of DPU Task's output Tensor.	
RETURNS	The start addresses to Task's output Tensor on success, or report error in case of any failure.	
SEE ALSO	dpuGetInputTensorAddress()	
INCLUDE FILE	n2cube.h	
AVAILABILITY	v1.07	

dpuGetOutputTensorSize()

NAME	dpuGetOutputTensorSize()	
SYNOPSIS	int dpuGetOutputTensorSize (DPUTask *task, const char*nodeName, int idx = 0);	
ARGUMENTS	task	The pointer to DPU Task.
	nodeName	The pointer to DPU Node's name. Note that the available names of one DPU Kernel's or Task's output Node are listed out after a neural network is compiled by DNNC. If invalid Node name specified, failure message is reported.
	idx	The index of a single output tensor for the Node, with default value as 0.
DESCRIPTION	Get the size (in Byte) of DPU Task's output Tensor.	
RETURNS	The size of Task's output Tensor on success, or report error in case of any failure.	
SEE ALSO	dpuGetInputTensorSize()	
INCLUDE FILE	n2cube.h	
AVAILABILITY	v2.06	

NAME	dpuGetOutputTensorSize()	
SYNOPSIS	int dpuGetOutputTensorSize (DPUTask *task, const char*nodeName);	
ARGUMENTS	task	The pointer to DPU Task.
	nodeName	The pointer to DPU Node's name. Note that the available names of one DPU Kernel's or Task's output Node are listed out after a neural network is compiled by DNNC. If invalid Node name specified, failure message is reported.
DESCRIPTION	Get the size (in Byte) of DPU Task's output Tensor.	
RETURNS	The size of Task's output Tensor on success, or report error in case of any failure.	
SEE ALSO	dpuGetInputTensorSize()	
INCLUDE FILE	n2cube.h	
AVAILABILITY	v1.07	

dpuGetOutputTensorScale()

NAME	dpuGetOutputTensorScale()	
SYNOPSIS	float dpuGetOutputTensorScale (DPUTask *task, const char*nodeName, int idx = 0);	
ARGUMENTS	task	The pointer to DPU Task.
	nodeName	The pointer to DPU Node's name. Note that the available names of one DPU Kernel's or Task's output Node are listed out after a neural network is compiled by DNNC. If invalid Node name specified, failure message is reported.
	idx	The index of a single output tensor for the Node, with default value as 0.
DESCRIPTION	Get the scale value of DPU Task's output Tensor. For each DPU output Tensor, it has one unified scale value indicating its quantization information for reformatting between data types of INT8 and FP32.	
RETURNS	The scale value of Task's output Tensor on success, or report error in case of any failure.	
SEE ALSO	dpuGetInputTensorScale()	
INCLUDE FILE	n2cube.h	
AVAILABILITY	v2.06	

NAME	dpuGetOutputTensorScale()	
SYNOPSIS	float dpuGetOutputTensorScale (DPUTask *task, const char*nodeName);	
ARGUMENTS	task	The pointer to DPU Task.
	nodeName	The pointer to DPU Node's name. Note that the available names of one DPU Kernel's or Task's output Node are listed out after a neural network is compiled by DNNC. If invalid Node name specified, failure message is reported.
DESCRIPTION	Get the scale value of DPU Task's output Tensor. For each DPU output Tensor, it has one unified scale value indicating its quantization information for reformatting between data types of INT8 and FP32.	
RETURNS	The scale value of Task's output Tensor on success, or report error in case of any failure.	
SEE ALSO	dpuGetInputTensorScale()	
INCLUDE FILE	n2cube.h	
AVAILABILITY	v1.07	

dpuGetOutputTensorHeight()

NAME	dpuGetOutputTensorHeight()	
SYNOPSIS	int dpuGetOutputTensorHeight (DPUTask *task, const char*nodeName, int idx = 0);	
ARGUMENTS	task	The pointer to DPU Task.
	nodeName	The pointer to DPU Node's name. Note that the available names of one DPU Kernel's or Task's output Node are listed out after a neural network is compiled by DNNC. If invalid Node name specified, failure message is reported.
	idx	The index of a single output tensor for the Node, with default value as 0.
DESCRIPTION	Get the height dimension of DPU Task's output Tensor.	
RETURNS	The height dimension of Task's output Tensor on success, or report error in case of any failure.	
SEE ALSO	dpuGetOutputTensorWidth() dpuGetOutputTensorChannel() dpuGetInputTensorHeight() dpuGetInputTensorWidth() dpuGetInputTensorChannel()	
INCLUDE FILE	n2cube.h	
AVAILABILITY	v2.06	

NAME	dpuGetOutputTensorHeight()	
SYNOPSIS	int dpuGetOutputTensorHeight (DPUTask *task, const char*nodeName);	
ARGUMENTS	task	The pointer to DPU Task.
	nodeName	The pointer to DPU Node's name. Note that the available names of one DPU Kernel's or Task's output Node are listed out after a neural network is compiled by DNNC. If invalid Node name specified, failure message is reported.
DESCRIPTION	Get the height dimension of DPU Task's output Tensor.	
RETURNS	The height dimension of Task's output Tensor on success, or report error in case of any failure.	
SEE ALSO	dpuGetOutputTensorWidth() dpuGetOutputTensorChannel() dpuGetInputTensorHeight() dpuGetInputTensorWidth() dpuGetInputTensorChannel()	
INCLUDE FILE	n2cube.h	
AVAILABILITY	v1.07	

dpuGetOutputTensorWidth()

NAME	dpuGetOutputTensorWidth()	
SYNOPSIS	int dpuGetOutputTensorWidth (DPUTask *task, const char*nodeName, int idx = 0);	
ARGUMENTS	task	The pointer to DPU Task.
	nodeName	The pointer to DPU Node's name. Note that the available names of one DPU Kernel's or Task's output Node are listed out after a neural network is compiled by DNNC. If invalid Node name specified, failure message is reported.
	idx	The index of a single output tensor for the Node, with default value as 0.
DESCRIPTION	Get the width dimension of DPU Task's output Tensor.	
RETURNS	The width dimension of Task's output Tensor on success, or report error in case of any failure.	

SEE ALSO	dpuGetOutputTensorHeight() dpuGetOutputTensorChannel() dpuGetInputTensorHeight() dpuGetInputTensorWidth() dpuGetInputTensorChannel()
INCLUDE FILE	n2cube.h
AVAILABILITY	v2.06

NAME	dpuGetOutputTensorWidth()	
SYNOPSIS	int dpuGetOutputTensorWidth (DPUTask *task, const char*nodeName);	
ARGUMENTS	task	The pointer to DPU Task.
	nodeName	The pointer to DPU Node's name. Note that the available names of one DPU Kernel's or Task's output Node are listed out after a neural network is compiled by DNNC. If invalid Node name specified, failure message is reported.
DESCRIPTION	Get the width dimension of DPU Task's output Tensor.	
RETURNS	The width dimension of Task's output Tensor on success, or report error in case of any failure.	

SEE ALSO	dpuGetOutputTensorHeight() dpuGetOutputTensorChannel() dpuGetInputTensorHeight() dpuGetInputTensorWidth() dpuGetInputTensorChannel()
INCLUDE FILE	n2cube.h
AVAILABILITY	v1.07

dpuGetOutputTensorChannel()

NAME	dpuGetOutputTensorChannel()	
SYNOPSIS	int dpuGetOutputTensorChannel (DPUTask *task, const char*nodeName, int idx = 0);	
ARGUMENTS	task	The pointer to DPU Task.
	nodeName	The pointer to DPU Node's name. Note that the available names of one DPU Kernel's or Task's output Node are listed out after a neural network is compiled by DNNC. If invalid Node name specified, failure message is reported.
	idx	The index of a single output tensor for the Node, with default value as 0.
DESCRIPTION	Get the channel dimension of DPU Task's output Tensor.	

RETURNS	The channel dimension of Task's output Tensor on success, or report error in case of any failure.
SEE ALSO	dpuGetOutputTensorHeight() dpuGetOutputTensorWidth() dpuGetInputTensorHeight() dpuGetInputTensorWidth() dpuGetInputTensorChannel()
INCLUDE FILE	n2cube.h
AVAILABILITY	V2.06

NAME	dpuGetOutputTensorChannel()	
SYNOPSIS	int dpuGetOutputTensorChannel (DPUTask *task, const char*nodeName);	
ARGUMENTS	task	The pointer to DPU Task.
	nodeName	The pointer to DPU Node's name. Note that the available names of one DPU Kernel's or Task's output Node are listed out after a neural network is compiled by DNNC. If invalid Node name specified, failure message is reported.
DESCRIPTION	Get the channel dimension of DPU Task's output Tensor.	

RETURNS	The channel dimension of Task's output Tensor on success, or report error in case of any failure.
SEE ALSO	dpuGetOutputTensorHeight() dpuGetOutputTensorWidth() dpuGetInputTensorHeight() dpuGetInputTensorWidth() dpuGetInputTensorChannel()
INCLUDE FILE	n2cube.h
AVAILABILITY	v1.07

dpuGetTensorAddress()

NAME	dpuGetTensorAddress()	
SYNOPSIS	int dpuGetTensorAddress (DPUTensor* tensor);	
ARGUMENTS	tensor	The pointer to DPU Tensor.
DESCRIPTION	Get the start address of DPU Tensor.	
RETURNS	The start address of Tensor, or report error in case of any failure.	
SEE ALSO	dpuGetInputTensorAddress() dpuGetOutputTensorAddress()	

INCLUDE FILE	n2cube.h
AVAILABILITY	v1.07

dpuGetTensorSize()

NAME	dpuGetTensorSize()	
SYNOPSIS	int dpuGetTensorSize (DPUTensor* tensor);	
ARGUMENTS	tensor	The pointer to DPU Tensor.
DESCRIPTION	Get the size (in Byte) of one DPU Tensor.	
RETURNS	The size of Tensor, or report error in case of any failure.	
SEE ALSO	dpuGetInputTensorSize() dpuGetOutputTensorSize()	

INCLUDE FILE	n2cube.h
AVAILABILITY	v1.07

dpuGetTensorScale()

NAME	dpuGetTensorScale()	
SYNOPSIS	float dpuGetTensorScale (DPUTensor* tensor);	
ARGUMENTS	tensor	The pointer to DPU Tensor.
DESCRIPTION	Get the scale value of one DPU Tensor.	
RETURNS	The scale value of Tensor, or report error in case of any failure. The users can perform quantization (Float32 to Int8) for DPU input tensor or de-quantization (Int8 to Float32) for DPU output tensor with this scale factor.	
SEE ALSO	dpuGetInputTensorScale() dpuGetOutputTensorScale()	
INCLUDE FILE	n2cube.h	
AVAILABILITY	v1.07	

dpuGetTensorHeight()

NAME	dpuGetTensorHeight()	
SYNOPSIS	float dpuGetTensorHeight (DPUTensor* tensor);	
ARGUMENTS	tensor	The pointer to DPU Tensor.
DESCRIPTION	Get the height dimension of one DPU Tensor.	
RETURNS	The height dimension of Tensor, or report error in case of any failure.	
SEE ALSO	dpuGetInputTensorHeight() dpuGetOutputTensorHeight()	
INCLUDE FILE	n2cube.h	
AVAILABILITY	v1.07	

dpuGetTensorWidth()

NAME	dpuGetTensorWidth()	
SYNOPSIS	float dpuGetTensorWidth (DPUTensor* tensor);	
ARGUMENTS	tensor	The pointer to DPU Tensor.
DESCRIPTION	Get the width dimension of one DPU Tensor.	

RETURNS	The width dimension of Tensor, or report error in case of any failure.
SEE ALSO	dpuGetInputTensorWidth() dpuGetOutputTensorWidth()
INCLUDE FILE	n2cube.h
AVAILABILITY	v1.07

dpuGetTensorChannel()

NAME	dpuGetTensorChannel()	
SYNOPSIS	float dpuGetTensorChannel (DPUTensor* tensor);	
ARGUMENTS	tensor	The pointer to DPU Tensor.
DESCRIPTION	Get the channel dimension of one DPU Tensor.	
RETURNS	The channel dimension of Tensor, or report error in case of any failure.	
SEE ALSO	dpuGetInputTensorChannel() dpuGetOutputTensorChannel()	
INCLUDE FILE	n2cube.h	
AVAILABILITY	v1.07	

dpuSetInputTensorInCHWInt8()

NAME	dpuSetInputTensorInCHWInt8()	
SYNOPSIS	int dpuSetInputTensorInCHWInt8 (DPUTask *task, const char*nodeName, int8_t *data, int size, int idx = 0)	
ARGUMENTS	task	The pointer to DPU Task
	nodeName	The pointer to DPU Node's name.
	data	The pointer to the start address of input data.
	size	The size (in Byte) of input data to be set.
	idx	The index of a single input tensor for the Node, with default value as 0.
DESCRIPTION	Set DPU Task input Tensor with data from a CPU memory block. Data is in type of INT8 and stored in Caffe Blob's order: channel, height and weight.	
RETURNS	0 on success, or report error in case of failure.	

SEE ALSO	`dpuSetInputTensorInCHWFP32()`
	`dpuSetInputTensorInHWCInt8()`
	`dpuSetInputTensorInHWCFP32()`	

INCLUDE FILE	n2cube.h	
AVAILABILITY	v2.06	

NAME	dpuSetInputTensorInCHWInt8()	
SYNOPSIS	int dpuSetInputTensorInCHWInt8 (DPUTask *task, const char*nodeName, int8_t *data, int size)	
ARGUMENTS	task	The pointer to DPU Task
	nodeName	The pointer to DPU Node's name.
	data	The pointer to the start address of input data.
	size	The size (in Byte) of input data to be set.
DESCRIPTION	Set DPU Task's input Tensor with data from a CPU memory block. Data is in type of INT8 and stored in Caffe Blob's order: channel, height and weight.	
RETURNS	0 on success, or report error in case of failure.	
SEE ALSO	dpuSetInputTensorInCHWFP32() dpuSetInputTensorInHWCInt8() dpuSetInputTensorInHWCFP32()	
INCLUDE FILE	n2cube.h	
AVAILABILITY	v1.07	

dpuSetInputTensorInCHWFP32()

NAME	dpuSetInputTensorInCHWFP32()	
SYNOPSIS	int dpuSetInputTensorInCHWFP32 (DPUTask *task, const char*nodeName, float *data, int size, int idx = 0)	
ARGUMENTS	task	The pointer to DPU Task
	nodeName	The pointer to DPU Node name.
	data	The pointer to the start address of input data.
	size	The size (in Bytes) of input data to be set.
	idx	The index of a single input tensor for the Node, with default value as 0.
DESCRIPTION	Set DPU Task's input Tensor with data from a CPU memory block. Data is in type of 32-bit-float and stored in Caffe Blob's order: channel, height and weight.	
RETURNS	0 on success, or report error in case of failure.	
SEE ALSO	dpuSetInputTensorInCHWInt8() dpuSetInputTensorInHWCInt8() dpuSetInputTensorInHWCFP32()	
INCLUDE FILE	n2cube.h	
AVAILABILITY	v2.06	

NAME	dpuSetInputTensorInCHWFP32()	
SYNOPSIS	int dpuSetInputTensorInCHWFP32 (DPUTask *task, const char*nodeName, float *data, int size)	
ARGUMENTS	task	The pointer to DPU Task
	nodeName	The pointer to DPU Node's name.
	data	The pointer to the start address of input data.
	size	The size (in Byte) of input data to be set.
DESCRIPTION	Set DPU Task's input Tensor with data from a CPU memory block. Data is in type of 32-bit-float and stored in Caffe Blob's order: channel, height and weight.	
RETURNS	0 on success, or report error in case of failure.	
SEE ALSO	dpuSetInputTensorInCHWInt8() dpuSetInputTensorInHWCInt8() dpuSetInputTensorInHWCFP32()	
INCLUDE FILE	n2cube.h	
AVAILABILITY	v1.07	

dpuSetInputTensorInHWCInt8()

NAME	dpuSetInputTensorInHWCInt8()	
SYNOPSIS	int dpuSetInputTensorInHWCInt8 (DPUTask *task, const char*nodeName, int8_t *data, int size, int idx = 0)	
ARGUMENTS	task	The pointer to DPU Task
	nodeName	The pointer to DPU Node name.
	data	The pointer to the start address of input data.
	size	The size (in Bytes) of input data to be set.
	idx	The index of a single input tensor for the Node, with default value of 0.
DESCRIPTION	Set DPU Task's input Tensor with data from a CPU memory block. Data is in type of INT8 and stored in DPU Tensor's order: height, weight and channel.	
RETURNS	0 on success, or report error in case of failure.	
SEE ALSO	dpuSetInputTensorInCHWInt8() dpuSetInputTensorInCHWFP32() dpuSetInputTensorInHWCFP32()	
INCLUDE FILE	n2cube.h	
AVAILABILITY	v2.06	

NAME	dpuSetInputTensorInHWCInt8()	
SYNOPSIS	int dpuSetInputTensorInHWCInt8 (DPUTask *task, const char*nodeName, int8_t *data, int size)	
ARGUMENTS	task	The pointer to DPU Task
	nodeName	The pointer to DPU Node's name.
	data	The pointer to the start address of input data.
	size	The size (in Byte) of input data to be set.
DESCRIPTION	Set DPU Task's input Tensor with data from a CPU memory block. Data is in type of INT8 and stored in DPU Tensor's order: height, weight and channel.	
RETURNS	0 on success, or report error in case of failure.	
SEE ALSO	dpuSetInputTensorInCHWInt8() dpuSetInputTensorInCHWFP32() dpuSetInputTensorInHWCFP32()	
INCLUDE FILE	n2cube.h	
AVAILABILITY	v1.07	

dpuSetInputTensorInHWCFP32()

NAME	dpuSetInputTensorInHWCFP32()	
SYNOPSIS	int dpuSetInputTensorInHWCFP32 (DPUTask *task, const char*nodeName, float *data, int size, int idx = 0)	
ARGUMENTS	task	The pointer to DPU Task
	nodeName	The pointer to DPU Node's name.
	data	The pointer to the start address of input data.
	size	The size (in Byte) of input data to be set.
	idx	The index of a single input tensor for the Node, with default value of 0.
DESCRIPTION	Set DPU Task's input Tensor with data from a CPU memory block. Data is in type of 32-bit-float and stored in DPU Tensor's order: height, weight and channel.	
RETURNS	0 on success, or report error in case of failure.	
SEE ALSO	dpuSetInputTensorInCHWInt8() dpuSetInputTensorInCHWFP32() dpuSetInputTensorInHWCInt8()	
INCLUDE FILE	n2cube.h	
AVAILABILITY	v2.06	

NAME	dpuSetInputTensorInHWCFP32()	
SYNOPSIS	int dpuSetInputTensorInHWCFP32 (DPUTask *task, const char*nodeName, float *data, int size)	
ARGUMENTS	task	The pointer to DPU Task
	nodeName	The pointer to DPU Node's name.
	data	The pointer to the start address of input data.
	size	The size (in Byte) of input data to be set.
DESCRIPTION	Set DPU Task's input Tensor with data from a CPU memory block. Data is in type of 32-bit-float and stored in DPU Tensor's order: height, weight and channel.	
RETURNS	0 on success, or report error in case of failure.	
SEE ALSO	dpuSetInputTensorInCHWInt8() dpuSetInputTensorInCHWFP32() dpuSetInputTensorInHWCInt8()	
INCLUDE FILE	n2cube.h	
AVAILABILITY	v1.07	

dpuGetOutputTensorInCHWInt8()

NAME	dpuGetOutputTensorInCHWInt8()	
SYNOPSIS	int dpuGetOutputTensorInCHWInt8 (DPUTask *task, const char*nodeName, int8_t *data, int size, int idx = 0)	
ARGUMENTS	task	The pointer to DPU Task
	nodeName	The pointer to DPU Node name.
	data	The start address of CPU memory block for storing output Tensor's data.
	size	The size (in Bytes) of output data to be stored.
	idx	The index of a single output tensor for the Node, with default value of 0.
DESCRIPTION	Get DPU Task's output Tensor and store its data into a CPU memory block. Data will be stored in type of INT8 and in Caffe Blob's order: channel, height and weight.	
RETURNS	0 on success, or report error in case of failure.	

SEE ALSO	dpuGetOutputTensorInCHWFP32() dpuGetOutputTensorInHWCInt8() dpuGetOutputTensorInHWCFP32()
INCLUDE FILE	n2cube.h
AVAILABILITY	v2.06

NAME	dpuGetOutputTensorInCHWInt8()	
SYNOPSIS	int dpuGetOutputTensorInCHWInt8 (DPUTask *task, const char*nodeName, int8_t *data, int size)	
ARGUMENTS	task	The pointer to DPU Task
	nodeName	The pointer to DPU Node's name.
	data	The start address of CPU memory block for storing output Tensor's data.
	size	The size (in Byte) of output data to be stored.
DESCRIPTION	Get DPU Task's output Tensor and store its data into a CPU memory block. Data will be stored in type of INT8 and in Caffe Blob's order: channel, height and weight.	
RETURNS	0 on success, or report error in case of failure.	

SEE ALSO	dpuGetOutputTensorInCHWFP32() dpuGetOutputTensorInHWCInt8() dpuGetOutputTensorInHWCFP32()
INCLUDE FILE	n2cube.h
AVAILABILITY	v1.07

dpuGetOutputTensorInCHWFP32()

NAME	dpuGetOutputTensorInCHWFP32()	
SYNOPSIS	int dpuGetOutputTensorInCHWFP32 (DPUTask *task, const char*nodeName, float *data, int size, int idx = 0)	
ARGUMENTS	task	The pointer to DPU Task
	nodeName	The pointer to DPU Node name.
	data	The start address of CPU memory block for storing output Tensor's data.
	size	The size (in Bytes) of output data to be stored.
	idx	The index of a single output tensor for the Node, with default value of 0.

DESCRIPTION	Get DPU Task's output Tensor and store its data into a CPU memory block. Data will be stored in type of 32-bit-float and in Caffe Blob's order: channel, height and weight.
RETURNS	0 on success, or report error in case of failure.
SEE ALSO	dpuGetOutputTensorInCHWInt8() dpuGetOutputTensorInHWCInt8(), dpuGetOutputTensorInHWCFP32()
INCLUDE FILE	n2cube.h
AVAILABILITY	v2.06

NAME	dpuGetOutputTensorInCHWFP32()	
SYNOPSIS	int dpuGetOutputTensorInCHWFP32 (DPUTask *task, const char*nodeName, float *data, int size)	
ARGUMENTS	task	The pointer to DPU Task
	nodeName	The pointer to DPU Node's name.
	data	The start address of CPU memory block for storing output Tensor's data.
	size	The size (in Byte) of output data to be stored.

DESCRIPTION	Get DPU Task's output Tensor and store its data into a CPU memory block. Data will be stored in type of 32-bit-float and in Caffe Blob's order: channel, height and weight.
RETURNS	0 on success, or report error in case of failure.
SEE ALSO	dpuGetOutputTensorInCHWInt8() dpuGetOutputTensorInHWCInt8(), dpuGetOutputTensorInHWCFP32()
INCLUDE FILE	n2cube.h
AVAILABILITY	v1.07

dpuGetOutputTensorInHWCInt8()

NAME	dpuGetOutputTensorInHWCInt8()
SYNOPSIS	int dpuGetOutputTensorInHWCInt8 (DPUTask *task, const char*nodeName, int8_t *data, int size, int idx = 0)

ARGUMENTS	task	The pointer to DPU Task
	nodeName	The pointer to DPU Node's name.
	data	The start address of CPU memory block for storing output Tensor's data.
	size	The size (in Byte) of output data to be stored.
	idx	The index of a single output tensor for the Node, with default value as 0.
DESCRIPTION	Get DPU Task's output Tensor and store its data into a CPU memory block. Data will be stored in type of INT8 and in DPU Tensor's order: height, weight and channel.	
RETURNS	0 on success, or report error in case of failure.	
SEE ALSO	dpuGetOutputTensorInCHWInt8() dpuGetOutputTensorInCHWFP32() dpuGetOutputTensorInHWCFP32()	
INCLUDE FILE	n2cube.h	
AVAILABILITY	v2.06	

NAME	dpuGetOutputTensorInHWCInt8()	
SYNOPSIS	int dpuGetOutputTensorInHWCInt8 (DPUTask *task, const char*nodeName, int8_t *data, int size)	
ARGUMENTS	task	The pointer to DPU Task
	nodeName	The pointer to DPU Node name.
	data	The start address of CPU memory block for storing output Tensor's data.
	size	The size (in Bytes) of output data to be stored.
DESCRIPTION	Get DPU Task's output Tensor and store its data into a CPU memory block. Data will be stored in type of INT8 and in DPU Tensor's order: height, weight and channel.	
RETURNS	0 on success, or report error in case of failure.	
SEE ALSO	dpuGetOutputTensorInCHWInt8() dpuGetOutputTensorInCHWFP32() dpuGetOutputTensorInHWCFP32()	
INCLUDE FILE	n2cube.h	
AVAILABILITY	v1.07	

dpuGetOutputTensorInHWCFP32()

NAME	dpuGetOutputTensorInHWCFP32()	
SYNOPSIS	int dpuGetOutputTensorInHWCFP32 (DPUTask *task, const char*nodeName, float *data, int size, int idx = 0)	
ARGUMENTS	task	The pointer to DPU Task
	nodeName	The pointer to DPU Node name.
	data	The start address of CPU memory block for storing output Tensor's data.
	size	The size (in Bytes) of output data to be stored.
	idx	The index of a single output tensor for the Node, with default value of 0.
DESCRIPTION	Get DPU Task's output Tensor and store its data into a CPU memory block. Data will be stored in type of 32-bit-float and in DPU Tensor's order: height, weight and channel.	
RETURNS	0 on success, or report error in case of failure.	

SEE ALSO	dpuGetOutputTensorInCHWInt8() dpuGetOutputTensorInCHWFP32() dpuGetOutputTensorInHWCInt8()
INCLUDE FILE	n2cube.h
AVAILABILITY	v2.06

NAME	dpuSetInputTensorInHWCFP32()	
SYNOPSIS	int dpuSetInputTensorInHWCFP32 (DPUTask *task, const char*nodeName, float *data, int size, int idx = 0)	
ARGUMENTS	task	The pointer to DPU Task
	nodeName	The pointer to DPU Node name.
	data	The pointer to the start address of input data.
	size	The size (in Bytes) of input data to be set.
	idx	The index of a single input tensor for the Node, with default value of 0.

DESCRIPTION	Set DPU Task's input Tensor with data from a CPU memory block. Data is in type of 32-bit-float and stored in DPU Tensor's order: height, weight and channel.
RETURNS	0 on success, or report error in case of failure.
SEE ALSO	dpuSetInputTensorInCHWInt8() dpuSetInputTensorInCHWFP32() dpuSetInputTensorInHWCInt8()
INCLUDE FILE	n2cube.h
AVAILABILITY	v2.06

NAME	dpuGetOutputTensorInHWCFP32()	
SYNOPSIS	int dpuGetOutputTensorInHWCFP32 (DPUTask *task, const char*nodeName, float *data, int size)	
ARGUMENTS	task	The pointer to DPU Task
	nodeName	The pointer to DPU Node's name.
	data	The start address of CPU memory block for storing output Tensor's data.
	size	The size (in Byte) of output data to be stored.

DESCRIPTION	Get DPU Task's output Tensor and store its data into a CPU memory block. Data will be stored in type of 32-bit-float and in DPU Tensor's order: height, weight and channel.
RETURNS	0 on success, or report error in case of failure.
SEE ALSO	dpuGetOutputTensorInCHWInt8() dpuGetOutputTensorInCHWFP32() dpuGetOutputTensorInHWCInt8()
INCLUDE FILE	n2cube.h
AVAILABILITY	v1.07

dpuRunSoftmax()

NAME	dpuRunSoftmax ()
SYNOPSIS	int dpuRunSoftmax (int8_t *input, float *output, int numClasses, int batchSize, float scale)

ARGUMENTS	input	The pointer to store softmax input elements in int8_t type.
	output	The pointer to store softmax running results in floating point type. This memory space should be allocated and managed by caller function.
	numClasses	The number of classes that softmax calculation operates on.
	batchSize	Batch size for the softmax calculation. This parameter should be specified with the division of the element number by inputs by numClasses.
	scale	The scale value applied to the input elements before softmax calculation. This parameter typically can be obtained by using DNNDK API dpuGetRensorScale().
DESCRIPTION	Perform softmax calculation for the input elements and save the results to output memory buffer. This API will leverage DPU core for acceleration if harden softmax module is available. Run “dexplorer -w” to view DPU signature information.	
RETURNS	0 for success.	
SEE ALSO	None	
INCLUDE FILE	n2cube.h	
AVAILABILITY	**V2.08**	

dpuSetExceptionMode()

NAME	dpuSetExceptionMode()	
SYNOPSIS	int dpuSetExceptionMode (int mode)	
ARGUMENTS	mode	The exception handling mode for runtime N^{2}Cube to be specified. Available values include: - *N2CUBE_EXCEPTION_MODE_PRINT_AND_EXIT* - *N2CUBE_EXCEPTION_MODE_RET_ERR_CODE*
DESCRIPTION	Set the exception handling mode for DNNDK runtime N^{2}Cube. It will affect all the APIs included in the libn2cube library. If N2CUBE_EXCEPTION_MODE_PRINT_AND_EXIT is specified, the invoked N^{2}Cube APIs will output the error message and terminate the running of DNNDK application when any error occurs. It is the default mode for N^{2}Cube APIs. If N2CUBE_EXCEPTION_MODE_RET_ERR_CODE is specified, the invoked N^{2}Cube APIs only return error code in case of errors. The callers need to take charge of the following exception handling process, such as logging the error message with API dpuGetExceptionMessage(), resource release, etc.	
RETURNS	0 on success, or negative value in case of failure.	
SEE ALSO	dpuGetExceptionMode() dpuGetExceptionMessage()	
INCLUDE FILE	n2cube.h	
AVAILABILITY	v2.08	

dpuGetExceptionMode()

NAME	dpuGetExceptionMode()
SYNOPSIS	int dpuGetExceptionMode()
ARGUMENTS	None
DESCRIPTION	Get the exception handling mode for runtime N^{2}Cube.
RETURNS	Current exception handing mode for N^{2}Cube APIs. Available values include: - *N2CUBE_EXCEPTION_MODE_PRINT_AND_EXIT* - *N2CUBE_EXCEPTION_MODE_RET_ERR_CODE*
SEE ALSO	dpuSetExceptionMode() dpuGetExceptionMessage()
INCLUDE FILE	n2cube.h
AVAILABILITY	v2.08

dpuGetExceptionMessage()

NAME	dpuGetExceptionMessage()	
SYNOPSIS	const char *dpuGetExceptionMessage (int error_code)	
ARGUMENTS	error_code	The error code returned by N2Cube APIs.
DESCRIPTION	Get the error message from error code (always negative value) returned by N^{2}Cube APIs.	

RETURNS	A pointer to a const string, indicating the error message for error_code.
SEE ALSO	dpuSetExceptionMode() dpuGetExceptionMode()
INCLUDE FILE	n2cube.h
AVAILABILITY	v2.08

Library libdputils

Overview

Library libdputils.so is the DPU utility library. It wraps up various highly optimized C/C++ APIs to facilitate DL applications development on DPU platform. The exported APIs are briefly summarized in the table below.

Notes:

- The following APIs are ONLY applicable to deploy Caffe model on DPU. For TensorFlow model, the users need to implement the pre-processing code (such as image scaling, normalization, etc.) to feed the input into DPU instead of using these APIs directly.

NAME	libdputils.so
DESCRIPTION	DPU utility library
ROUTINES	dpuSetInputImage() – set DPU Task's input image with mean values specified from network model dpuSetInputImage2() – set DPU Task's input image without mean values dpuSetInputImageWithScale() – set DPU Task's input image according to the given scale value Note: The three APIs of dpuSetInputImage(), dpuSetInputImage2() and dpuSetInputImageWithScale() automatically rescales the input images to

	match the input dimension of the used model via invoking OpenCV resize().The image interpolation method adopted is INTER_LINEAR.
INCLUDE FILE	dputils.h

APIs

The prototype and parameter for each API of library libdputils are shown in detail in the following sections.

dpuSetInputImage()

NAME	dpuSetInputImage ()	
SYNOPSIS	int dpuSetInputImage (DPUTask *task, const char *nodeName, const cv::Mat &image, float *mean, int idx = 0)	
ARGUMENTS	task	The pointer to DPU Task.
	nodeName	The pointer to DPU Node name. Note that the available names of one DPU Kernel or Task output Node are listed out after a neural network is compiled by DNNC. If invalid Node name specified, failure message is reported.
	image	Input image in OpenCV Mat format. Single channel and 3-channel input image are supported.

	mean	Pointer to mean value array which contains 1 member for single channel input image or 3 members for 3-channel input image. Note: You can get the mean values from the input Caffe prototxt. At present, the format of mean value file is not yet supported.
	idx	The index of a single input tensor for the Node, with default value as 0.
DESCRIPTION	set DPU Task input image	
RETURNS	0 on success, or report error in case of any failure.	
SEE ALSO	dpuSetInputImageWithScale ()	
INCLUDE FILE	dputil.h	
AVAILABILITY	v2.06	

NAME	dpuSetInputImage ()
SYNOPSIS	int dpuSetInputImage (DPUTask *task, const char *nodeName, const cv::Mat &image, float *mean)

ARGUMENTS	task	The pointer to DPU Task.
	nodeName	The pointer to DPU Node's name. Note that the available names of one DPU Kernel's or Task's output Node are listed out after a neural network is compiled by DNNC. If invalid Node name specified, failure message is reported.
	image	Input image in OpenCV's Mat format. Single channel and 3-channel input image are supported.
	mean	Pointer to mean value array which contains 1 member for single channel input image or 3 members for 3-channel input image. Note: You can get the mean values from the input Caffe prototxt. At present, the format of mean value file is not yet supported.
DESCRIPTION	set DPU Task's input image	
RETURNS	0 on success, or report error in case of any failure.	
SEE ALSO	dpuSetInputImageWithScale ()	
INCLUDE FILE	dputil.h	
AVAILABILITY	v1.07	

dpuSetInputImage2()

NAME	dpuSetInputImage2 ()
SYNOPSIS	int dpuSetInputImage2 (

	DPUTask *task, const char *nodeName, const cv::Mat &image, int idx = 0)	
ARGUMENTS	task	The pointer to DPU Task.
	nodeName	The pointer to DPU Node name. Note that the available names of one DPU Kernel or Task output Node are listed out after a neural network is compiled by DNNC. If invalid Node name specified, failure message is reported.
	image	Input image in OpenCV's Mat format. Single channel and 3-channel input image are supported.
	idx	The index of a single input tensor for the Node, with default value as 0.
DESCRIPTION	set DPU Task input image without specify the mean value	
RETURNS	0 on success, or report error in case of any failure.	
SEE ALSO	dpuSetInputImageWithScale ()	
INCLUDE FILE	dputil.h	
AVAILABILITY	v2.06	

NAME	dpuSetInputImage2 ()
SYNOPSIS	int dpuSetInputImage2

	(DPUTask *task, const char *nodeName, const cv::Mat &image)	
ARGUMENTS	task	The pointer to DPU Task.
	nodeName	The pointer to DPU Node's name. Note that the available names of one DPU Kernel's or Task's output Node are listed out after a neural network is compiled by DNNC. If invalid Node name specified, failure message is reported.
	image	Input image in OpenCV's Mat format. Single channel and 3-channel input image are supported.
DESCRIPTION	set DPU Task's input image without specify the mean value	
RETURNS	0 on success, or report error in case of any failure.	
SEE ALSO	dpuSetInputImageWithScale ()	
INCLUDE FILE	dputil.h	
AVAILABILITY	v1.10	

dpuSetInputImageWithScale()

NAME	dpuSetInputImageWithScale ()
SYNOPSIS	int dpuSetInputImageWithScale (DPUTask *task, const char *nodeName,

	const cv::Mat &image, float *mean, float scale, int idx=0)	
ARGUMENTS	task	The pointer to DPU Task.
	nodeName	The pointer to DPU Node name. Note that the available names of one DPU Kernel's or Task output Node are listed out after a neural network is compiled by DNNC. If invalid Node name specified, failure message is reported.
	image	Input image in OpenCV Mat format. Single channel and 3-channel input image are supported.
	mean	Pointer to mean array which containing 3 elements **Note**: you can get the mean values from the input Caffe prototxt and mean file is not supported so far.
	scale	Scale value of input image
	idx	The index of a single input tensor for the Node, with default value as 0.
DESCRIPTION	Set DPU Task input image with the mean value and scale specified from network model	
RETURNS	0 on success, or report error in case of any failure.	
SEE ALSO	dpuSetInputImage ()	
INCLUDE FILE	dputil.h	
AVAILABILITY	v2.06	

NAME	dpuSetInputImageWithScale ()	
SYNOPSIS	int dpuSetInputImageWithScale (DPUTask *task, const char *nodeName, const cv::Mat &image, float *mean, float scale)	
ARGUMENTS	task	The pointer to DPU Task.
	nodeName	The pointer to DPU Node name. Note that the available names of one DPU Kernel's or Task output Node are listed out after a neural network is compiled by DNNC. If invalid Node name specified, failure message is reported.
	image	Input image in OpenCV Mat format. Single channel and 3-channel input image are supported.
	mean	Pointer to mean array which containing 3 elements **Note**: you can get the mean values from the input Caffe prototxt and mean file is not supported so far.
	scale	Scale value of input image
DESCRIPTION	set DPU Task input image with the mean value and scale specified from network model	
RETURNS	0 on success, or report error in case of any failure.	
SEE ALSO	dpuSetInputImage ()	

INCLUDE FILE	dputil.h
AVAILABILITY	v1.07

Since v3.1, DNNDK begins to support Python programming APIs to deploy Caffe or TensorFlow models on the DPU platform. And most of Python APIs are kept identical with C++ APIs for the user's smoothly switching between them. The users can refer to DNNDK Python samples to get more understanding about Python APIs' usage.

In order to avoid large space of repetitions, those APIs identical with C++ aren't covered here. The users can refer to Chapter 12: C++ Programming APIs. Only such APIs being changed are illustrated in this chapter. In addition, the users can use `print __doc__` for each Python API to learn more detailed info.

Notes:

- For C++ APIs of library `libn2cube.so`, the corresponding Python APIs are defined in the module `n2cube`. For C++ APIs of library `libdputils.so`, the corresponding Python APIs are defined in the module `dputils`. And `n2cube` and `dputils` two modules are packaged into one Python dnndk package.

Module n2cube

Overview

Most of Python APIs in module n2cube are identical with C++ APIs in library libn2cube. The differences between them are listed below, which are also described in the subsequent sections.

- `dpuGetOutputTensorAddress()`: the type of return value different from C++ API.
- `dpuGetTensorAddress()`: the type of return value different from C++ API.
- `dpuGetInputTensorAddress()`: not available for Python API.

APIs

The prototype and parameter for those changed Python APIs of module dputils are described in detail in the following sections.

dpuGetOutputTensorAddress()

NAME	dpuGetOutputTensorAddress()
SYNOPSIS	dpuGetOutputTensorAddress (

	task, nodeName, idx = 0)	
ARGUMENTS	task	The ctypes pointer to DPU Task.
	nodeName	The string DPU Node's name. **Note**: the available names of one DPU Kernel's output nodes are listed out after network model is compiled by DNNC. If invalid node name is specified, failure message will be reported.
	idx	The index of a single output tensor for the Node, with default value as 0.
DESCRIPTION	Get the ctypes pointer that points to the data of DPU Task's output Tensor. **Note**: For C++ API, it returns int8_t type start address of DPU Task's output Tensor.	
RETURNS	Return ctypes pointer that points to the data of DPU Task's output Tensor. Using together with dpuGetTensorData, the users can get output Tensor's data.	
SEE ALSO	dpuGetTensorData ()	
MODULE	n2cube	
AVAILABILITY	V3.1	

dpuGetTensorAddress()

NAME	dpuGetTensorAddress()	
SYNOPSIS	dpuGetTensorAddress (tensor)	
ARGUMENTS	tensor	The ctypes pointer to DPU Tensor.
DESCRIPTION	Get the ctypes pointer that points to the data of DPU Tensor. Note: For C++ API, it returns int8_t type start address of DPU Tensor.	
RETURNS	Return ctypes pointer that points to the data of DPU Tensor. Using together with dpuGetTensorData, the users can get Tensor's data.	
SEE ALSO	dpuGetTensorData ()	
MODULE	n2cube	
AVAILABILITY	V3.1	

dpuGetTensorData()

NAME	dpuGetTensorData()
SYNOPSIS	dpuGetTensorData (tensorAddress, data,

	tensorSize)	
ARGUMENTS	tensorAddress	The ctypes pointer to the data of DPU Tensor.
	data	The list to store the data of DPU Tensor.
	tensorSize	Size of DPU Tensor data in byte.
DESCRIPTION	Get the DPU Tensor's data.	
RETURNS	None.	
SEE ALSO	dpuGetOutputTensorAddress ()	
MODULE	n2cube	
AVAILABILITY	V3.1	

Module dputils

All of Python APIs in module dputils are completely identical with C++ APIs in library libdputils.

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